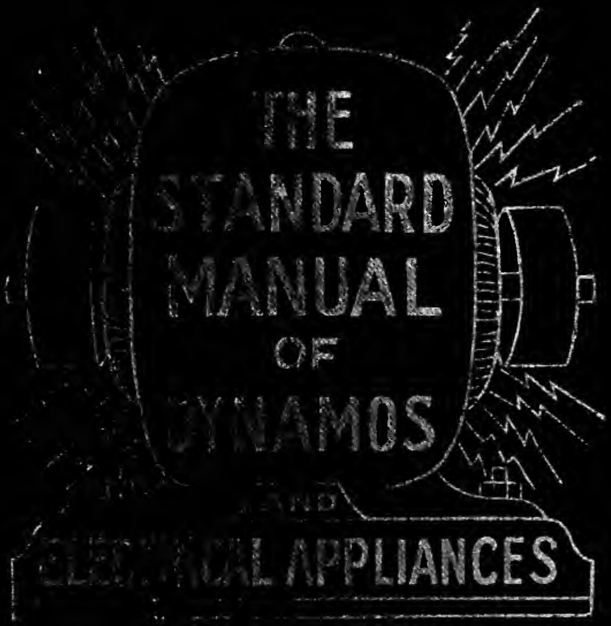
THE
STANDARD
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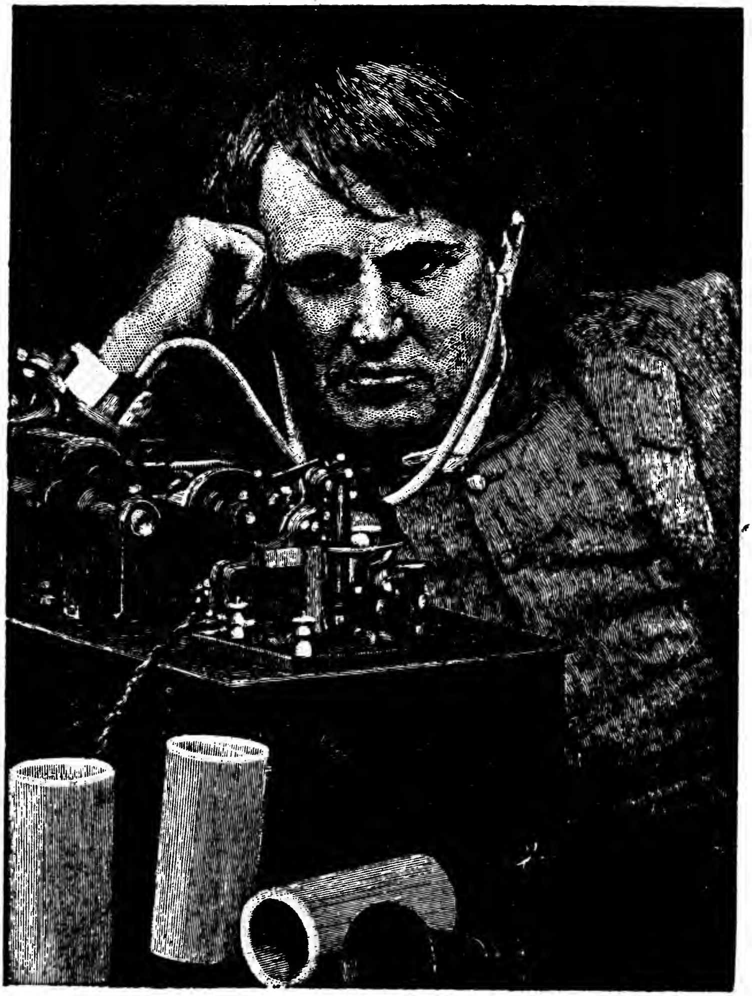

THOMAS A. EDISON

THE

STANDARD MANUAL OF DYNAMOS

AND

PRACTICAL APPLICATION OF
DYNAMO-ELECTRIC MACHINERY

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Preface.

Our aim in bringing out this little book has been to reach a class of readers who, realizing the need of a general fundamental understanding of the application of Electricity, will read with some benefit, we trust, a few descriptions of the modus operandi of the most generally used class of Electrical Machinery.

It has not been our intention to take up the subjects treated on, in any but the most simple and as we believe, the most easily understood way.

It is becoming more necessary each year for the well qualified steam engineer to be somewhat familiar with Dynamo Electric Machinery in order to advance in his calling. A partial understanding at least is now or soon will be almost a necessity for those engaged in nearly all branches of engineering work. There is hardly a profession which electricity in some way has not entered. The vast majority of the men in charge of our practical work have never had the advantage of a technical education and are therefore unable to follow the advances that are so rapidly being made.

The volt, ampere, and ohm and their relations to each other are the first stumbling blocks and the cause is easily seen by inspecting a few books for definitions of these words.

We have endeavored to impress as much as possible, the formula expressing Ohms Law,

$$C = \frac{E}{R}$$

on which all calculations necessarily take their start. A

thorough understanding of the relations of the volt, ampere and ohm to each other, is without doubt the foundation of *all* electrical knowledge.

We have also endeavored to keep up to the times and believe we give some interesting descriptions of modern electrical apparatus, which will be of value to those whose main source of light on electrical matters come from catalogues and newspapers.

The dynamo tender, unless partially conversant with the principles on which his machinery operates, will often be perplexed at even the most trivial troubles to which a dynamo is subject. A motorman on our usual electric street cars, could often lessen motor repairs to a great extent by obtaining even an elementary understanding of the motors' action. An understanding of the proper distribution and installation of electric wires would be the means of averting many thousands of dollars loss each year by fire from electrical causes.

There are many good books on the various branches of electrical work but they are too often of such a technical nature as to bar the uneducated reader from obtaining much benefit from them, We hope that a close study of the following pages will place the average beginner on such a foundation as to make the other more complete electrical books more easily understood.

CARL K. MACFADDEN.
June 1, 1894. WM. D. RAY.

CHAPTER I.

ELEMENTARY DATA.

What is electricity? A question often asked and probably never as yet clearly answered.

Those interested in the practical field, find it almost impossible to keep up to the times, in regard to the laws that govern its generation and control. We know that by means of certain combinations of coils of wire and magnets or by means of chemical action, we can produce, we may say, electricity.

We must be content if we master a few leading laws governing the generation and application of the Electric current. Let the Scientists and Philosophers discuss the question as to what electricity is. In dealing with the simple electric current that is generated by dynamos, batteries, etc., we will find that there are several broad and easily understood laws that govern its practical applications. These laws hold good in all cases and under all conditions, and should be thoroughly understood by anyone desiring to learn even the first and most simple effects of a flow of electric current.

Probably the easiest way to understand this law will be to take a simple case of a pump connected to a loop of water pipe. The pipe is filled with water and it is evident that if the pump is started there will be a circulation of water from the pump through the pipe and back into

the pump again. The pump furnishes the power to move the water in the pipe—and it is evident that the water moves through the pipe owing to the pressure exerted by the pump on the water. In (figure 1) an open tank, (d) is shown into which the water flows from the pipe. The pump takes the water from the tank to keep the pipe filled, and the speed of the water through the

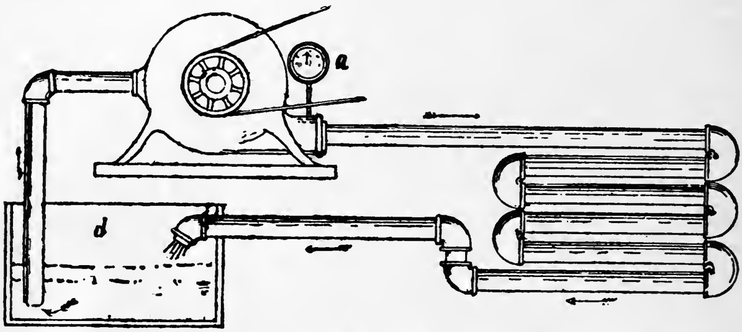


FIGURE I.—PUMP FORCING WATER THROUGH PIPES.

pipe and therefore the quantity of water passing through the pump and pipe in a minute of time, will depend on the pressure given the water by the pump.

If we double the pressure of the water and the friction or resistance to the flow of water in the pipe remains constant, the quantity of water handled by the pump will be doubled. In other words by increasing the pressure, we increase the quantity of water passing through the pipe at exactly the same ratio. Now if we found that a guage placed at (a) would have to register 50 lbs. pressure to make 100 gallons of water pass through the pipe in a minute, it is evident that if the friction in the pipe remained the same, that 100 lbs. pressure ought to put 200 gallons through the pipe. It is also evident that

if 100 feet of pipe a certain size offers a definite amount of friction, that twice the length of pipe would have two times the friction or resistance to the flow of water that the 100 feet has. Thus to put 100 gallons of water a minute through a pipe will take ½ the pressure required to force 200 gallons through the pipe. This example may serve the purpose of illustrating the principle of the flow of current from a source of electricity. We will let the dynamo take the place of the pump, which will generate the pressure to send the electricity through the circuit which may consist of lamps, etc., connected by means of conducting wires. The friction in the pipe is represented by the "resistance" of the wire and circuit, and the amount of water used, represent the quantity of the current of electricity.

Instead of using the pound as the unit of water pressure we will use the term "volt" which is the unit of electrical pressure. We also have a term which denotes the unit of "resistance, which is the equivalent of "friction" used in the illustration of the pump and pipe. The unit of resistance is called the "ohm."

Then lastly the *quantity* of current in electricity is measured by the unit of current quantity, the "ampere." This is the quantity of current that a pressure of one volt will force through a resistance of 1 ohm.

The resistance of a conductor of electricity varies not only with its size or cross section but also with the material of which it is made. Silver, when pure, is the best conductor of electricity known, but copper, when pure, nearly approaches silver and is so much cheaper that it is used in nearly all cases to distribute current for practical purposes.

The metals in their order for conductivity are as follows: Silver, Copper, Gold, Aluminum, Zinc, Platinum, Iron, Lead, German Silver, Platinum Silver alloy and Mercury.

In practice the wires or conductors to carry current are either designated in size by their diameter in thousandths of an inch (or mils) or by the sectional area or cross section of the wire expressed in circular mils or by the size in number, as measured by the Standard American or Brown & Sharp Wire Guage.

A circular mil is a circle $\frac{1}{1000}$ inch in diameter.

As in the case of pump, the higher the pressure in volts at the dynamo, the larger quantity of electricity (expressed in amperes) will be put through a circuit which has a resistance (expressed in ohms) to the flow of current.

Thus if 1 volt pressure will force 1 ampere of current through a circuit having 1 ohm of resistance, it will take 5 volts to force 5 amperes through this same 1 ohm of resistance and if this resistance is increased to 2 ohms, the pressure would have to be 10 volts to force 5 amperes of current through it.

It will be seen that these terms are dependent on each other and their relation to each other is expressed by what is known as Ohms Law which is expressed:

$$\text{Current in Amperes} = \frac{\text{Pressure in Volts}}{\text{Resistance in Ohms}} \quad \text{or} \quad C = \frac{E}{R}$$

"C" standing for current, "E" for electro-motive force or volts, and "R" for resistance expressed in "Ohms." This relation $C=E/R$ must be remembered for it is the fundamental law of the governing of electric currents, and is used as a foundation to obtain all of the more com-

plex formulas known to the Electrical Engineers.

Take the simple case of a certain make of incandescent lamp, the resistance of the lamp in question is found to be 200 ohms The pressure of the circuit on which this lamp is designed to run is 100 volts, and according to Ohms law the current in amperes which 100 volts pressure will force through 200 ohms of resistance is $\frac{100}{200}$ or ½ which is the number of amperes such a lamp would allow to pass through it if current at 100 volts pressure was applied.

It will thus be seen that it is a very easy matter to obtain any one of these quantities, provided we have the other two given, by a simple multiplying or dividing of the two known quantities. The relations to each other are expressed

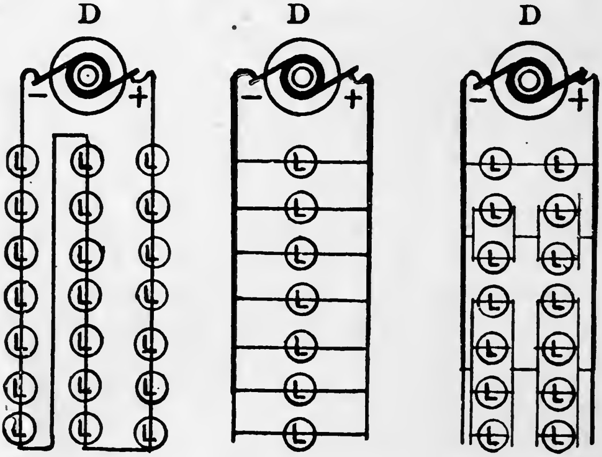
$$C = \frac{E}{R}, \quad E = R \times C, \text{ and } R = \frac{E}{C}.$$

There is still another term with which the practical man is brought in contact and that is the unit of power, the "watt." This watt is the *power* represented by the passing of 1 ampere of current through 1 ohm of resistance and can always be obtained of any current by multiplying the number of volts by the number of amperes.

Thus in the incandescent lamp before spoken of, the watts used by the lamp would be 100 (volts)x½ (amp) = 50 (the number of watts), this being the amount of electrical energy necessary to be applied continually to keep the lamp burning. Such an incandescent lamp would be termed "a 50 watt incandescent lamp." An arc lamp which needed a current of 10 amperes at a pressure of 50 volts to keep it in operation would be termed a "500 watt arc lamp".

There are two entirely different methods of distributing current to lamps etc., connected to dynamos.

The plan illustrated by means of the pump in (figure 1) may be seen as applied to a dynamo and lamps in (figure 2) (a), in which the dynamo D supplies current for lamps L and is known as the Series System. It will be seen in plan (a) that the lamps are connected in "series" that is, the current which passes out from the positive (+)



Series (*a*) *Multiple or Parallel* (*b*) *Mulliple Series* (*c*)

FIGURE 2.—SYSTEMS OF CURRENT DISTRIBUTION.

brush of the dynamo must go through the whole series of lamps before the negative (—) brush is reached, the number of amperes flowing through the wire will be found to be the same at whatever point it is measured, but the pressure in volts will vary with the number of lamps through which current is forced. If each of the lamps required 10 amperes of current to bring it up to candle power. and it took 50 volts pressure to put 10 amperes of current through it, or in other words, if the lamp had 5

ohms resistance, then the dynamo would have to generate 50 volts for every lamp in the series of lamps or on a 10 lamp circuit the voltage would be 500, 20 lamps 1000 volts and so on. Such a system of lighting is used in operating the usual type of "Series arc lamps." The current in amperes remains nearly constant, but the voltage at the dynamo varies with the number of lamps through which it has to force current.

Plan (b), figure 2 shows the Multiple System or the system of placing lamps in parallel or multiple arc. The dynamo (D) furnishes current of a uniform pressure to lamps (L) connected to the mains marked (+) and (—)the current from the dynamo however varies as to its quantity in amperes, on the number of paths through the lamps from the positive to the negative mains. This plan of current distribution is used in furnishing current to the usual incandescent lamps, or in any other work requiring a uniform pressure or voltage. It will thus be seen that the multiple system is the opposite from the series system in several ways. In the series system the larger the number of lamps the higher the pressure in volts, although the current in amperes remains constant, while in the multiple system the voltage remains practically uniform and the amperes given out by the dynamo varies with the number of lamps connected between the mains.

The Multiple-Series plan of distribution is a combination of both the previous methods and is shown in plan (c) figure 2. This system of wiring is used to operate arc lamps on incandescent or constant potential circuits and in the other special places which will be spoken of later on in Chapter IV.

746 watts are equal to 1 electrical horse power and by dividing the output of a dynamo in watts by 746 we can obtain the output of the dynamo in electrical horse-power or E. H. P.

1000 watts = 1 kilo watt and is a term generally used to give the rating of generators or dynamos. The abbreviation K. W., is used to express kilo-watt. It is evident that the term kilo-watt as used to describe a dynamo does not denote the voltage, or the current in amperes, which the dynamo may be designed to generate. It simply means, for example, in a 1 kilo watt generator, that the generator has a capacity of supplying 1000 watts of electricity, which may be represented by 1 ampere at 1000 volts pressure, 1000 amperes at 1 volt, 10 amperes at 100 volts, 100 amperes at 10 volts or any other combination of current that equals 1000 watts, as the case may be.

A proper description of such a generator would be, for instance, a 1 kilo watt, 100 volt generator, which of course lets us know that such a dynamo will generate 10 amperes at the 100 volt pressure, thus making one thousand watts or one kilo-watt. Hence Watts or W. =C x E the product of amperes and volts.

The instruments used for measuring electrical pressure in volts are generally called voltmeters, or pressure indicators. Those for measuring amperes or quantity are called ammeters.

The resistance in ohms is measured usually by means of an instrument called the Wheatstone bridge, or rarely an ohmmeter.

Wattmeters are used for measuring watts, or the product of volts and amperes.

CHAPTER II.

MAGNETISM AND INDUCTION.

Inasmuch as the generation of dynamo electricity is effected by means of the action of magnetism, it is well to take up the subject of magnets first.

A magnet, as known to practice, is a piece of iron or steel, which has the power of attracting other pieces of iron to it. There are two types of magnets, permanent magnets, and electro-magnets. A permanent magnet is usually made of hard tempered steel, which after having been brought under the influence of some magnetizing apparatus, retains a more or less amount of magnetism. We often see them in horse-shoe form, known as horse-shoe magnets. Large permanent magnets, however, are expensive to make, and are extremely weak in comparison to their weight, and in addition they seldom hold their magnetism for any length of time.

The other type, known as the electro-magnet, is quite a different thing. If a piece of iron has wound around it, a few turns of insulated wire, and a current of electricity be passed through the wire, the iron immediately will be magnetized, and will remain magnetized as long as the current passes through the wire. The moment, however, the current through the wire is stopped the iron is no longer magnetized. Thus

it is seen that the current in passing around the iron has an effect on it, and magnetizes it.

The amount of magnetism shown by the iron centre of the coil will depend on two factors, the number of turns of wire around the core of iron, and the number of amperes of current passing around through the turns. Thus with 10 amperes passing around the core, 20 turns of wire will have twice the magnetizing power that 10 turns will have. The effect will depend on what is known as the number of "ampere turns" in the coil of wire, the ampere turns being the product of the number amperes and turns, thus, if we have 10 turns and 10 amperes passing through them, we have a coil of 100 ampere turns, which will have ½ the effect that 200 ampere turns will have. It is evident, that 100 turns with one ampere passing through them, will have the same effect as 50 amperes and 2 turns, or 100 amperes and one turn, each of the above quantities being equal to 100 ampere turns.

We have practically no limit as to the strength of the magnet we may construct. The very powerful magnets used in dynamos lately constructed, are made by winding an immense number of turns on large iron cores, and then sending currents of electricity through them, thus making a large number of ampere turns, and producing an immense magnetic effect.

Iron has been spoken of as the cores for the magnets because it is the metal found to be capable of carrying more magnetism than any other. In any coil of wire carrying an electric current we may imagine a large number "lines of magnetism" being generated by the current, each line starting from the end of the magnet

called the positive end and taking a path through the air or some magnetic material back to the other end of the coil called the negative end. These little loops are thrown out from the end of the coil and will follow the easiest path back to the other end, thus completing a magnetic circuit. A permanent magnet made of hardened steel throws out these same little loops from its poles without being excited by means of the passage of a current of electricity around it.

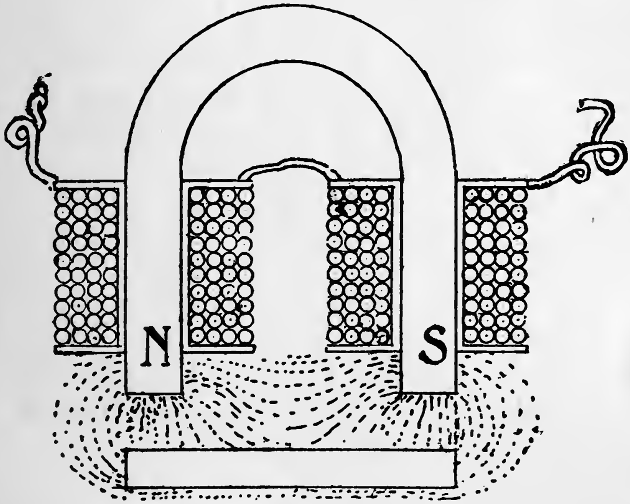


FIGURE 3.—ELECTRO-MAGNET AND ARMATURE SHOWING LINES OF MAGNETISM.

If a piece of iron or steel is placed in such a position with relation to the coil as to be in the magnetic influence or "field," a large number of these lines of magnetism will take the path through the iron in preference to that through the air owing to the fact that iron will

carry lines of magnetism better than air or any other material. The iron under these conditions will tend to assume the position in which the largest number of the lines of force or magnetism will pass through it, and for this reason iron is "attracted" to the coil or magnet. Some iron carries these lines thousands of times better than air. Figure (3) shows the action on a horse-shoe magnet made of soft iron, having a coil of wire on each limb.

The nearer the armature or "keeper" of the horse-shoe magnet approaches the ends of the magnet, the stronger will be the pull, owing to the increased number of lines of magnetism it carries. A compass needle points north and south because in that position the metal of the compass is parallel to and is carrying more of the lines of the Earth's magnetism through it, than at any other position.

If a coil of wire is wound on a hollow spool of wood or other non-magnetic material, and a current of electricity be passed through the coil, it will be found that a piece of iron will be drawn up into the coil of wire and tend to assume a central position in the coil. On stopping the flow of current through the coil, the iron core will no longer be attracted. When the core of the coil or "selonoid" as it is called, is in its centre, it is carrying the maximum number of lines of magnetism.

The selonoid is a form of magnet often used in the manufacture of arc lamps, etc., and is adapted for this purpose on account of the large movement of the core compared to that of the armature, or keeper of the usual type of electro-magnet with an iron centre.

There is still another wonderful effect of magnetism, that of *induction*. If a magnet be moved about in the

vicinity of a coil of wire whose ends are connected to a means for measuring the passage of an electric current, it will be found that a current of electricity will be generated in the wire of the coil, and that it flows only when the magnet is being moved near the coil. Also, that as the magnet moves toward the coil, that the current flows in one direction through the coil, and as it is being pulled away, the current flows in an opposite direction.

By arranging a suitable set of coils and magnets, in such manner that the coils pass in front of the magnets, we may be able to generate strong currents of electricity, and in fact, all dynamos and generators are operated on this plan. The usual method employed is to so mount an electro magnet, called the field magnet, that there is a break in the iron magnetic circuit, across which the lines of magnetism will pass in completing their circuit. In this gap in the magnetic circuit, an armature consisting of a number of coils of insulated wire mounted on a shaft, is revolved by means of power applied to it. As these coils of insulated wire move through the lines of magnetism, currents of electricity are generated in them which are carried away from the armature, to the lamp, etc., to which the dynamo is connected.

CHAPTER III.

THEORY OF DYNAMOS.

An electric generator or dynamo is a combination of coils of wire and magnets, which have a movement with relation to each other and which, when supplied with suitable mechanical power will generate currents of electricity.

In practice, they consist without exception of an armature in which the currents of electricity are generated, and a field magnet or magnets which furnish the lines of magnetism, through which the coils of wire on the armature pass, and thus generate current.

The armature may be, and usually is, the moving part; but this is not by any means a necessary thing, for the field magnets may be made the moving part with the armature stationary and accomplish the same result. At present the stationary armature is found only on a few types of dynamos which are usually used for generating alternating currents. It has been shown that the movement of a coil of wire with its ends connected, in the vicinity or magnetic field of a stationary magnet, will generate currents of electricity in the coil. If the coil of wire *approaches* the magnet, the flow of current will be in one direction, and if it is *drawn away*, the current will flow in an opposite direction through the coil. If the coil is held stationary near the mag-

net, no current will be generated in it. This is all caused by the coil of wire passing through, or "cutting", the lines of magnetism. The current generated, depends however, on several factors. In the first place let us construct, for illustration, the simplest possible form of a dynamo. To furnish the lines of magnetism, we will use a simple steel horse-shoe shaped permanent magnet, **M**, see figure 4.

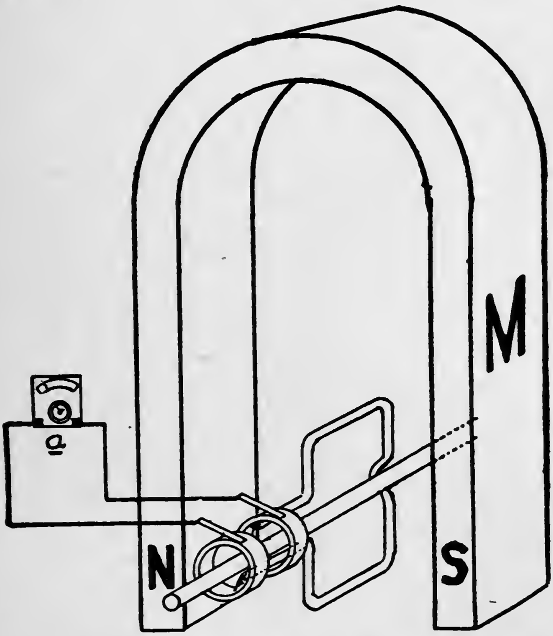


FIGURE 4.—SINGLE LOOP ARMATURE WITH COLLECTOR RINGS, REVOLVING BETWEEN POLES OF PERMANENT MAGNET.

On a shaft we mount a coil of wire consisting of one convolution, the ends of which are connected to insu-

lated rings mounted at one end of the shaft and on which two brushes bear, and thus connect the coil of wire to a suitable measuring instrument(a). In the diagram we will assume that the lines of magnetism are being concentrated between the poles N and S; N being the north and S the south. Thus if the coil of wire on the armature is revolved on its shaft, it is evident that with the coil in the position shown, will have its right hand half moving down before the pole S, and the left hand half moving upward before the pole N, and since we assume that there are an immense number of lines of magnetism flowing through the space from N to S, it is evident that the moving coil must "cut" these lines, and it is this action that generates current, or to be more correct, generates electrical pressure which expends itself in creating a flow of current, the amount depending on the resistance of the circuit. Assuming that the lines of magnetism from the permanent field magnets, remains constant, we will find that the electrical pressure generated, and thus the current will depend on simply the *rate* at which these lines of magnetism are cut, if at 1000 revolutions per minute the coil of a single turn will generate 5 volt pressure, 2000 revolutions per minute will generate 10 volts pressure. The direction in which the current will flow, will depend on the direction of movement of the conductor through the lines of magnetism.

In a simple loop, whose ends are connected to rings, mounted on shaft as shown in figure 4, the current through half a revolution will flow through the coil in one direction, and in the remaining half revolution the current will flow in an opposite direction. Thus in a

complete revolution, the current will flow first in one direction, and then reverse and flow in an opposite direction, and in this way produces what is known as an *alternating current.* This alternating type of current can only be used for certain kinds of work, and to so arrange the connections that all the impulses or waves of current generated in the armature will be given out in one direction, a commutator is necessary. The action of the com-

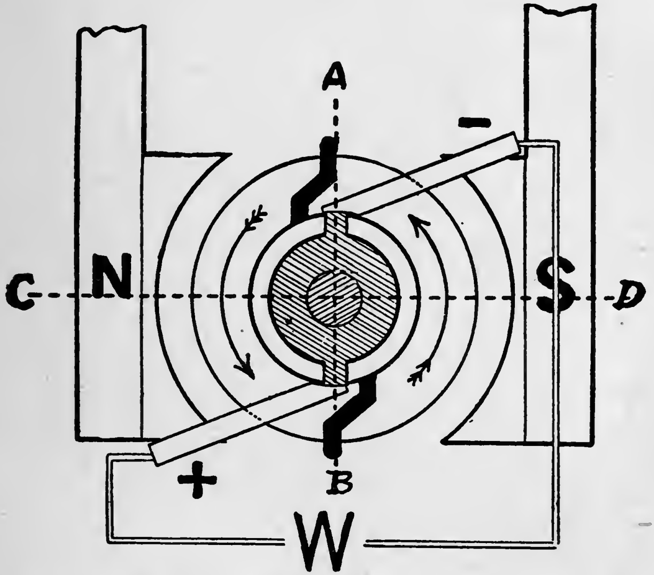


FIGURE 5.—SINGLE LOOP. ARMATURE ON IRON CORE WITH COMMUTATOR AND BRUSHES.

mutator may be understood from study of figure 5, which shows the same loop of wire between the poles of a magnet, as was shown in figure 4, with the exception that instead of rings mounted in the shaft, with brushes

bearing on them a split ring is shown, each half of which is connected to a terminal of the single armature coil of one turn (c). The two half rings are insulated from each other and from the armature shaft, and the action may be described as follows:—From the point (A) figure 5 to the point (B) which is ½ revolution, the current flows in such a direction as to make the brush (+) a positive brush, that is, the current flows from + to —,

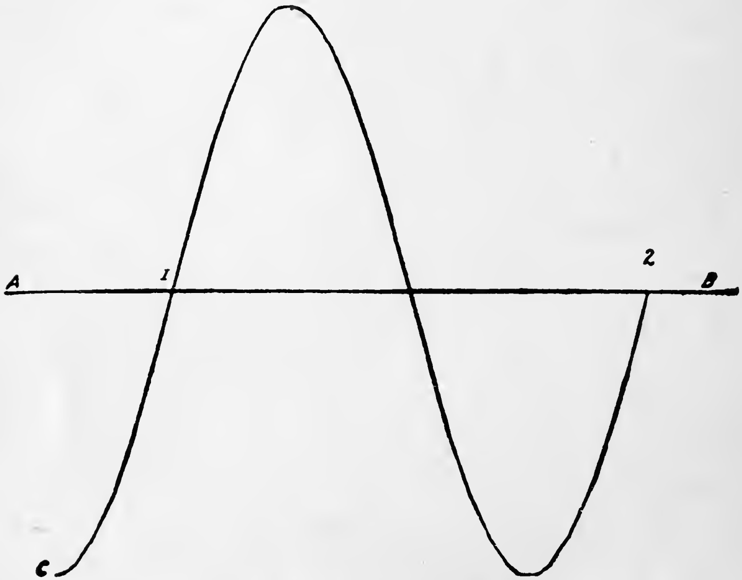


FIGURE 6.—ALTERNATING CURRENT WAVE.

the current generated depending on the rate at which lines of magnetism are being cut by the loop of wire. The current with the loop at the line (A-B) will be zero, for this is the point at which the current is reversing its direction in the loop, owing to the fact that

the direction in which the loop cuts the lines of magnetism is being changed. From this position on dotted line A—B, the current will gradually rise to a maximum when the loop is on the line C—D, which is the point at which a certain given movement of the loop will cut the greatest number of lines of force. The rise and fall of current in an alternating current circuit may be shown readily by the cut in figure 6. The line A—B representing the zero line or line of no flow of current in the coil. The distance from 1 to 2 represents one complete revolution and the curved line C represents the current produced by the revolving loop. The portion of the curved line above the zero line represents current flowing in a positive direction and the portion below the line will represent the negative flow of current. The total curve from 1 to 2, represents one complete alternation, which in the combination shown in figure 4, means one revolution. If we had the coil making 2000 revolutions per minute, there would be 2000 of such waves as shown in curve 1—2. With a commutator such as shown in figure 5, and with the brushes placed as shown, it will be seen that just as the current in the coil is at zero the commutator has moved in such a position that the brushes are just changing from one segment of the commutator to the other, thus keeping the rising side of the loop connected to the negative brush and the downward moving side of the loop connected to the positive brush. In this way we can send all the impulses or waves of current from the revolving coil on the circuit in one direction, thus producing a pulsating current, but at the same time one whose flow is always in one direction. The current curve of such a dynamo will now be

such as shown in figure 7, in which it will be noticed all of the waves of current are above the zero line A—B. This type of current is known as a direct current of pulsating character. As before stated the generator, or dynamo just spoken of, is of the simplest possible form and to make large dynamos for supplying continuous direct current in an economical manner such a primitive dyna-

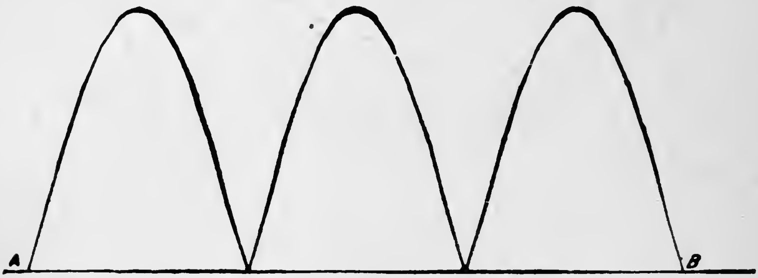


FIGURE 7.—PULSATING DIRECT CURRENT WAVE—SINGLE COIL ARMATURE.

mo as shown, must be greatly improved. In chapter I, we have spoken of electro-magnets as being the only practical form for large and powerful magnets, and we will find that all field magnets for large dynamos are of this type.

The armatures of large dynamos, instead of having but a single coil, will often have 100 or more coils, each consisting of one or more turns, for if a single turn coil will generate, for instance, 1 volt, when cutting the magnetic lines at a given rate, a coil of 10 turns of wire in it will generate 10 times the pressure that the 1 turn will, or 10 volts. And as has been explained, if a piece of iron be placed in a magnetic field, a large number of the lines of

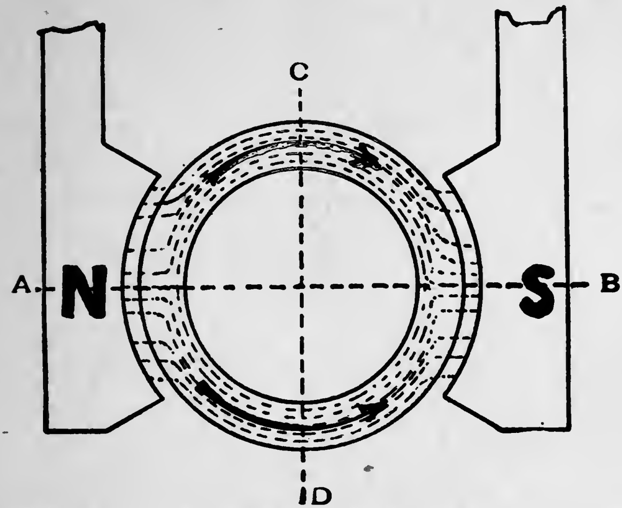


FIGURE 8.—FLOW OF MAGNETISM THROUGH A RING ARMATURE CORE.

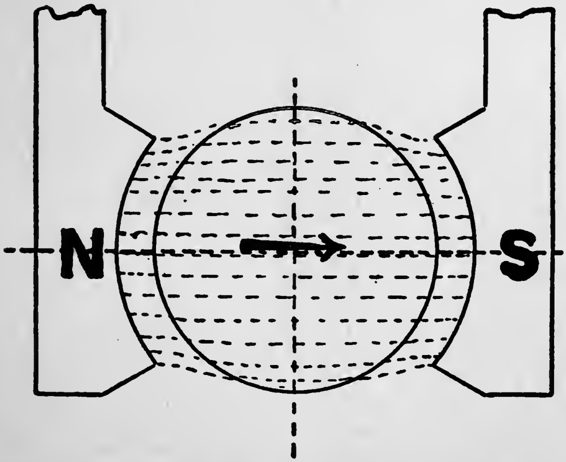


FIGURE 9.—FLOW OF MAGNETISM THROUGH A DRUM ARMATURE CORE.

magnetism will take to the iron in completing their individual circuits, and so it has been found advisable to wind armature coils on an iron core, so that the largest possible number of lines of magnetism flowing from the poles of the field magnets, will flow through the iron armature cores, and in this way, the coils of the armature will cut a larger portion of the lines given out by the field magnets.

The reader will easily understand, from the previous description, that the current given out from a single coil armature may be a direct current, but still of a pulsating type, there being in the cases shown, two impulses in each revolution.

There are many cases where such a pulsating current would be nearly as objectionable as an alternating current. To overcome this trouble and to also make a dynamo whose efficiency is high enough for practical work, has taken an immense amount of study. To make the principal used to obtain a continuous current, very clear to the reader, it will be well to take up the case of a "ring" armature on which a single coil is wound.

From figure 8 and 9, it will be seen that nearly all the lines of magnetism shown between the pole pieces take the iron path in preference to the air. In the case of the iron ring shown between the pole pieces, N and S, the lines practically divide on the line A—B half taking their path by way of the upper half of the ring, and the remaining half through the lower portion of the ring. Thus with a coil placed as in figure 10, it is evident that practically only the wire on the outer face of the ring will be cutting the lines of magnetism as they pass from the pole pieces to the ring. The coil will generate a

current while revolving from C to D, the line C—D being the neutral line, or line of commutation, which is the point at which the current will reverse its direction in the moving coil. This is the simplest form of ring armature, a step in advance is the adding of a coil

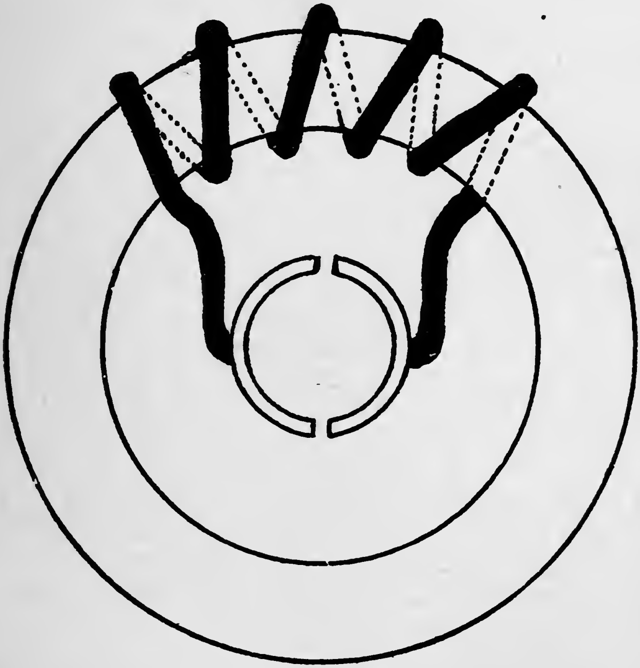


FIGURE 10.—RING ARMATURE OF ONE COIL

on the opposite side of the ring, and connecting them in multiple, that is, the current generated by one coil has added to it the current of the other coil, which adds whatever current it may be generating, to that of the original coil. In this case, the amounts generated in

two coils will be equal, for when the coil on one side of the ring is generating current, the coil diametrically opposite must also be generating a like amount, and when connected in multiple as shown the total result at the brushes will be the sum of the two effects. See figure 11. It will be evident also, that while the coils are

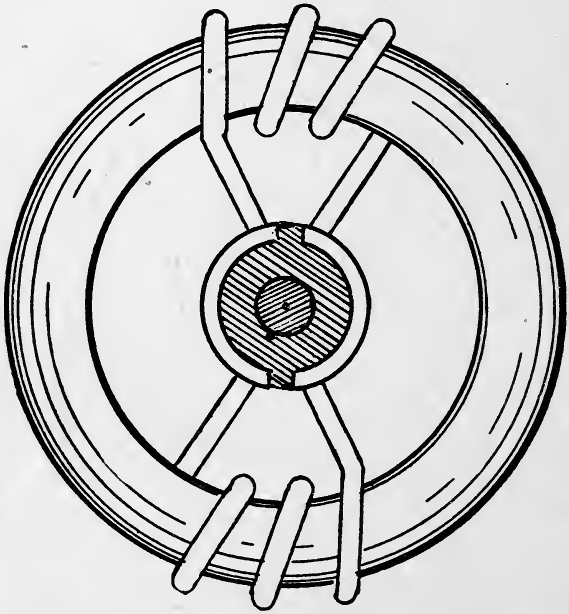


FIGURE 11.—RING ARMATURE.—TWO COILS IN MULTIPLE.

moving past the line C–D, fig. 8, they generate no current, since they cut practically no lines of magnetism, and that if two coils were placed on the ring so as to be moving past the line, A—B, they would be generating a maximum amount of current. By connecting these four

coils as shown in figure 12, we will generate a current having twice as many impulses as in the case of an armature having but one pair of coils in series. The current wave will be represented by figure 13. The line 1—2 representing one revolution.

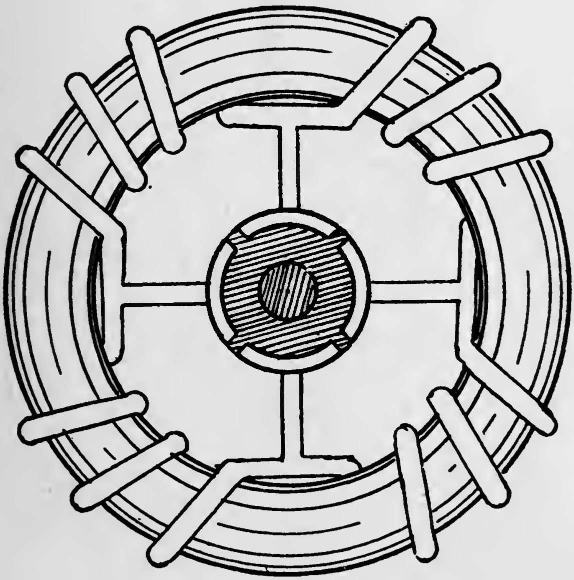


FIGURE 12.—GRAMME RING ARMATURE.
FOUR COIL TYPE.

This multiplying of coils can be carried on with economy, until we have some dynamos of this type, having hundreds of coils, and giving practically a perfectly continuous current.

The proper placing of the armature coils in the magnetic field between the pole pieces of the field magnets,

has taken an immense amount of study and experiment, and we to-day have two general types of armature, the drum and the ring type. The drum armatures are so called from their shape. A cylindrical piece of iron with the armature shaft running through its length from end to end, is covered with coils of wire, which in dynamos

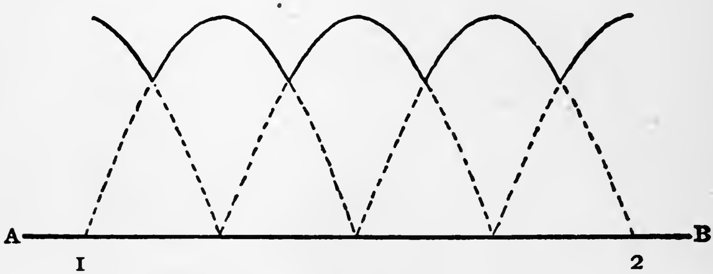


FIGURE 13.—CURRENT WAVES OF FOUR COIL RING ARMATURE.

having but two field magnet poles, are so wound as to form loops similar to that shown in figure 5. This type of armature, with many coils each of several turns, is the type usually used for incandescent lighting and power work by direct currents. The drum armature is sometimes called Siemens armature, from its inventor. Dynamos having ring armatures have been used to a great extent for arc light work and are certainly a very much easier armature to repair than drum armatures, whose windings usually cross and overlap at the ends of the iron armature cores, and thus increase the liability to make trouble from

short circuits etc., at these points, which often make it necessary to remove nearly all the armature windings to repair the damaged coil. Ring armatures or Gramme armatures as they are often called, may be repaired quickly by removing the defective coil from the ring, and rewinding with a new coil, or in many cases of

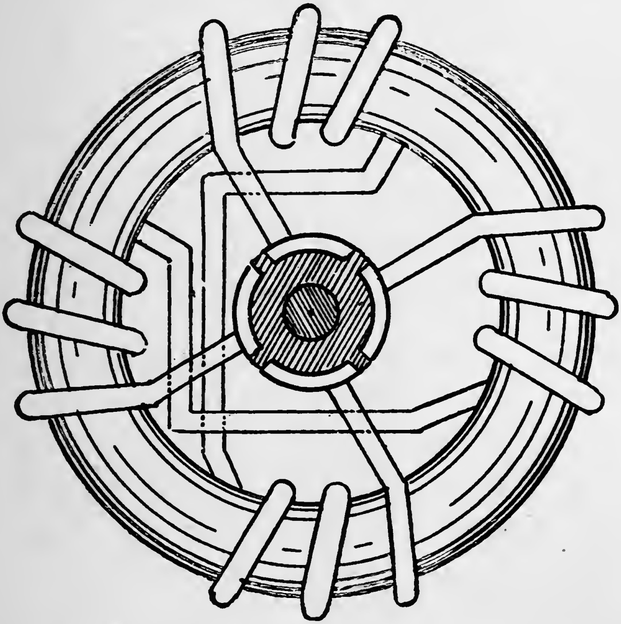


FIGURE 14.—OPEN COIL RING ARMATURE.

trouble, the damaged coil may be disconnected from the commutator bars, and the two bars to which the coil was connected are then connected by a short piece of wire, and the dynamo will then be able to generate current until repairs are made.

The first arc light dynamos, the Brush and Thompson-Houston makes, have armatures of the ring form, but owing to the peculiar windings on them, cannot be called Gramme armatures. They are known as "open coil" armatures, while all Gramme ring and drum armatures are known as "closed coil". This distinction is brought about from the fact that drum and ring armatures are, as has been shown, connected between windings or segments, of commutator, in such a way as to leave the armature windings always connected in a permanent way from coil to coil, whereas in open coil armatures as shown in figure 12, it will be seen that the coils are separate and distinct from each other.

In both the Brush and Thomson-Houston dynamos, the armature coils are provided with terminals which alter the connections in such a manner as to let the coils in the most active positions give the bulk of the current, and either cut out the less active coils entirely, as in Brush dynamos, or reduce the resistance of such coils to the flow of current by placing them in parallel or multiple arc, and then in series with the active coil or coils.

The current from both of the dynamos mentioned, is extremely pulsating, compared to current from the usual ring armature, but owing to the well worked out details of construction, insulation, regulation, and to the reliability derived therefrom, both Brush and Thomson-Houston arc dynamos are known the world over. Chas. F. Brush, of Cleveland, Ohio, was the pioneer in arc lighting work as the world now knows it, and Profs. Elihu Thomsom and Edw. J. Houston were not far behind him in pioneer work.

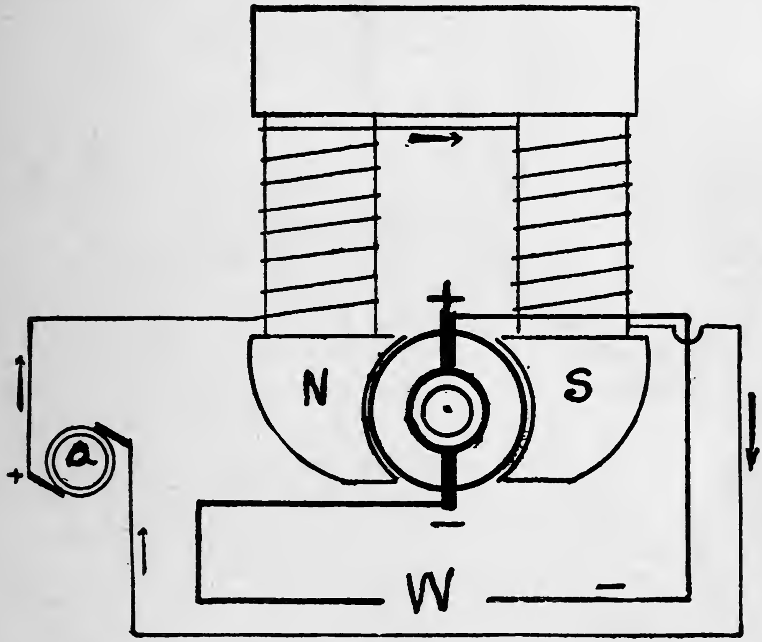


FIGURE 15.—SEPARATELY EXCITED DYNAMO.

We have taken up the fundamental study of armatures and have spoken of electro-magnets for field magnets, and the various methods in vogue for energizing them will now be taken up. It takes a current of electricity, passing around an iron core or center to make an electro magnet, the power of which will vary with the ampere

turns, or the product of the number of amperes passing and the number of turns of wire around the iron core. The first dynamos built with electro magnets for field magnets were "separately excited," that is, had a separate battery or generator of electricity to furnish current

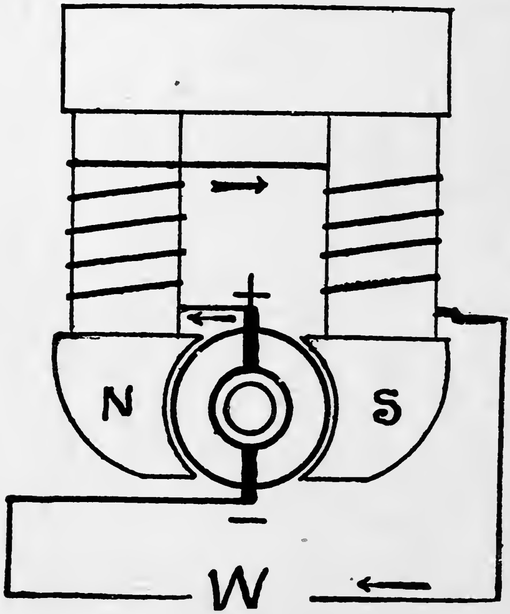


FIGURE 16.—SERIES WOUND DYNAMO.

to energize them, the plan of connections being shown in figure 15. Then it was seen that the current from the dynamo itself might be used to excite its own field magnets and owing to a slight amount of "residual magnetism", which always remains in a piece of iron after having once been magnetized, being present in the field

magnets, this was easily accomplished, as shown in figure 16, and is known as a "series winding" and such a dynamo would be known as a "series wound" dynamo. The field winding carries the whole current of the armature and is connected in series with it. This winding is

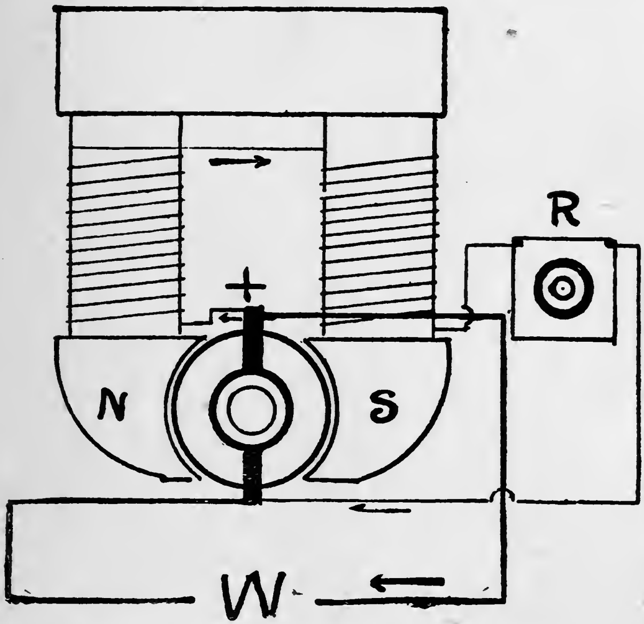


FIGURE 17.—SHUNT WOUND DYNAMO.

generally used in arc light dynamos, and others generating a constant current of high voltage.

The plan of a shunt winding is shown in figure 17, and is so called from the fact that the winding forms a "shunt" path around the armature. To make an efficient dynamo, the resistance of the shunt winding is made

quite high, several hundred times the resistance of the armature and as a result, the current through the shunt is small in quantity, but the immense number of turns of small size wire in the coils on the field magnets make the necessary number of ampere turns, and thus the resultant magnetism is the same as that produced in the series dynamo with its large current and small number of turns. Shunt wound dynamos are usually used to generate currents of "constant potential" or "constant voltage" such as is used in operating incandescent lamps, electric motors, etc. Owing to the high cost of wire necessary for shunt windings for dynamos of high voltage, we will find that practically all shunt dynamos operate at a voltage under 600, in fact, by far the largest number of shunt dynamos operate at a voltage of not over 125 volts. For regulating purposes a rheostat (R) containing resistance wire, is placed in the shunt circuit, and in this way a practically uniform voltage is maintained at all loads by varying the total resistance of the shunt circuit, and thus the current through it, which must in turn vary the magnetism of the field and in this way raise or lower the voltage, as the case may require.

Still another winding is shown in figure 18, known as the compound winding, and is often used to make a dynamo self-regulating It is evident, that on a constant potential circuit when additional lamps are turned on, that the dynamo must respond at once and send out a larger number of amperes to take care of the load. Under these conditions, to maintain the voltage constant, we must increase the magnetism of the field magnets to compensate for the increased output. This may be accomplished in an automatic manner by winding a large

portion of the field with a shunt winding, which should be of such strength as to generate the rated voltage of the dynamo when there is no load placed on it. Then the series windings must be sufficient to add enough ampere turns as the load rises, to keep the voltage up to standard or in some "over compounded" dynamos to increase the

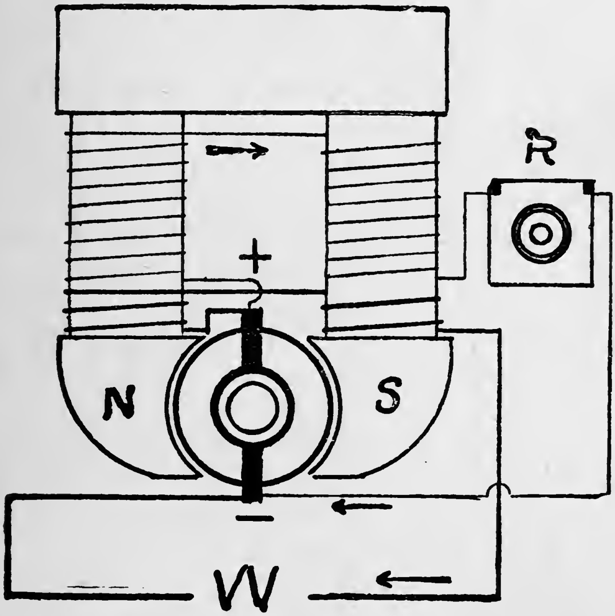


FIGURE 18.—COMPOUND WOUND DYNAMO.

voltage slightly as the load increases, so as to compensate for loss in line or feeders supplying lamps, etc. This type of dynamo is largely used in lighting plants having a fluctuating load, and is invariably the type used to generate current for street railway work, where the load is an ever varying quantity, a condition under which the

compound wound dynamo is practically the only one which gives satisfaction.

There are a number of modifications of these principal windings which are seldom run across and for this reason are not explained in detail; suffice to say, that dynamos can be, and have been made, which, by means of the principles described, will give a constant current and varying voltage, a constant voltage and a varying current, in both cases the speed being maintained uniform, or as in some cases of dynamos designed to be connected to the axle of a car for train lighting, the voltage remains practically uniform, with a varying current, while the speed alters several hundred per cent.

It will be seen that we have various types of armatures and field magnets with their various windings, and it will be be easy to see that it is possible to build dynamos of almost any size, and for any kind or character of current.

CHAPTER IV.

CURRENT DISTRIBUTION.

In the previous chapters, we have treated of direct and alternating current dynamos, and to a certain extent, their application. In this chapter we take up the methods of distributing current to lamps, motors, etc., all of which are deserving of much study.

The dynamo for lighting or power purposes, usually sends current a considerable distance before it is used in the arc or incandescent lamps, motors, etc.

It is evident that it is desirable to have as little loss as possible in power, between the dynamo or generator and the point at which the current is used.

For this reason, conductors of copper are used, owing to its "conductivity," that is, its small resistance to the flow of current. But even in the purest copper, there is some resistance, the amount varying with the length, and also with the diameter or "cross-section" of the copper. If we attempt to reduce the loss to a very small amount, the cost of copper will be high and if there is not enough copper, the loss in pressure will be excessive.

To prevent a loss of current from the conductors, from them accidentally coming in contact with the ground or other conductors of electricity, the wires are insulated from each other and from all connections to the ground. In high potential work, this insulating of conductors

would have to be done for safety to human life, for pressure of 600 volts and over are exceedingly dangerous.

The distribution of current for series arc lighting is a simple matter, since the current in amperes is constant and uniform in all parts of the circuit and the loss in one portion of the wire circuit will be the same as in any similar length of the same size wire. Thus in calculating losses in the wiring leading to arc lamps in series circuits, the main thing to determine is the total resistance of the wire, and, having the resistance in ohms, we easily calculate the number of volts lost in passing the 6, 8 or 10 amperes, as the case may be, through the wire. The loss in volts will be the number of amperes, multiplied by the number of ohms or, expressed in symbols of ohms law, $E=C\times R$.

Thus, on an arc light circuit 10 miles long, consisting of No. 6 B & S Guage Wire, which we may see from consulting the wire table in the back of book, has a resistance of practically, 2 ohms per mile (2.088) that with 10 amperes of current flowing, that the loss in volts, per mile, will be 10×2 or 20 volts, 10 miles would thus be 200 volts, which is the pressure required to force the current through the wire circuit, this being independent of the number of arc lamps in series, each one of which adds from 45 to 50 volts to the 200. Thus a circuit, 10 miles long, of No. 6 wire and 50—50 volt lamps connected in series on it, will take a total electro-motive force in volts of 200 (line resistance) + 2500, which is the total voltage required for the lamps themselves (50×50) which makes a total of 2700 volts required to force 10 amperes through the circuit with its lamps. The loss in volts being 200, and the total voltage necessary to operate the

lamps on such a circuit, being 2700, it is evident that the per cent. of loss on such a circuit will be $\frac{2700}{200}$, or nearly 7½%, which in practice would not be considered excessive. If No. 4 B and S wire were used in place of No. 6, the loss would have been only 130 volts or 5% loss, but the extra cost of copper wire provided with a good rubber insulation, would have been nearly $800 over a No. 6 wire and the extra loss in current is not enough to pay for putting up a No. 4 wire. Smaller wire than No. 6 can hardly be recommended, however, on account of the increased trouble in keeping up a long line of small wire which is likely to be broken easily by sleet, wind, etc.

Incandescent lamps are sometimes connected in series in the same manner as arc lamps; but the current will usually be found to be less than 5 amperes, although there are some series incandescent lamps made to run on 10 ampere circuits in series with arc lamps. Owing to the danger connected with the handling of such series incandescent lamps, due to the high voltage on which they usually operate, they are not in very general use and are being discarded more and more each year for indoor illumination.

It will be seen that in any series circuit that if the circuit be broken at any point that it will stop the flow of current through all the lamps connected and for this reason all arc and incandescent lamps designed for series work are provided with "cut out" which preserves the circuit in case of trouble with an individual lamp, so as to allow the remaining lamps to operate. In arc lamps on series circuits, the cut out "short circuits," the lamp in case of the carbon being consumed or broken or in case of a carbon rod in the lamp, sticking or "hanging

up." In the case of incandescent circuits, there is usually provided a socket for the lamp in which is a cut out, designed to preserve the continuity of the circuit in case from a lamp being broken or removed from its socket. Arc lamps for series circuits are nearly always operated on direct current dynamos. However the arc lamp is being adapted to the alternating current more and more and wil probably replace the greater part of direct current arc service.

The second and without doubt the most generally used plan of current distribution for either power or illuminating purposes, is that by means of the constant potential dynamo and a multiple or multiple series system of distribution. Practically, all incandescent lighting, all distribution of current for power purposes and quite a portion of recent arc lighting plants are furnished with current from constant potential dynamos of either alternating and direct types.

To distribute current at a constant potential or voltage, great care must be exercised in designing the plan of wiring to be used, for it is a very necessary thing to have the pressure in volts as near a constant quantity as possible. This will be found especially the case in incandescent lamp installation. A slight rise of voltage above that for which the lamps are designed, will decrease the life of the lamp to an alarming extent. A slight reduction in the voltage, will increase the life to a great extent but the light given out by the lamp will decrease so much as to be unsatisfactory,

The method of calculating the size of wire for constant potential distribution may be easily understood after a study of the relation of size of wire to its resistance. A copper wire 98% pure, which is $\frac{1}{1000}$ of an inch or one

circular mil. in cross section, will be found to measure 10.355 ohms per foot of length, at a temperature of 20° Centigrade or 68° Fahrenheit. Knowing the resistance of a wire one mil in diameter and one foot long to be 10.355 ohms, we may then calculate the resistance of any wire, provided we know its length in feet and area in circular mils. On a foot length, a wire 2 circular mils in cross section will have but half the resistance of the wire having one circular mil area or 5.1775 ohms per foot length. The smallest wire usually carried in stock by dealers in wire for magnets, etc., is 25 C. M. in area and is known as a No. 36 wire and has a resistance of .4142 ohms per foot of length or $\frac{1}{25}$ as much as a wire 1 C.M. in area. The smallest wire used in wiring for incandescent lamps and other electric light distribution (No. 16 B. & S.) has an area of 2583 C. M. and a resistance at 68° Fahrenheit of .004009 ohms per foot of length. A No. 6 B. & S. copper wire which has been spoken of as a very largely used size for distribution of arc light current on series circuits, has an area of 26,250 C. M. and a resistance of .0003944 ohms per foot. The temperature of the wire has an effect on the resistance of the metal of which it is made. Copper wire increases its resistance as the temperature rises, but for ordinary conditions the rise is so slight that it need not be considered. Knowing the resistance of a certain size wire in ohms per unit length and the distance to lamps or motors from the source of current, we may easily calculate the loss or drop in volts with a given current in amperes passing, by means of the equation, $V = C \times R$, or, the volts lost will equal the number of amperes multiplied by the total resistance, expressed in ohms, of the copper wire. It must be remem-

bered that we must look at the loss in the wiring as a distinct and separate expenditure of power, which is entirely independent of that taken by lamps, motors, etc. to which the wiring conveys current.

We have shown how the loss in volts may be calculated, provided we know the total resistance of the conducting wires and the current passing through them. The condition most usually encountered is that where the maximum number of volts available to overcome conductor resistance is known, and also the distance to the lamps from the source of supply. The unknown quantity is the area or size of the wire necessary to carry the amount of current needed at lamps, etc., with the loss in volts decided on.

On electric light plants, for example, where 110 volt incandescent lamps are used, we will find that the voltage, at the dynamo, will probably be from 115 to 125 volts, depending on the distance from the dynamo to the lamps, the difference between 110 volts and the voltage found at the dynamos, being the number of volts used to overcome the resistance of the conducting wires. Dynamos for supplying direct current for constant potential work are usually shunt or compound wound and by means of a rheostat in series with the field magnet circuit, can have their voltage raised as the load increases, so as to maintain a uniform voltage at the lamps. This energy or power lost, shows itself in heating the copper conductors and of course is a loss which must be made as low as possible without an excessive outlay for copper wire. The loss in watts in a given conductor varies with the square of the number of amperes passing through it Thus, in a conductor having 1 ohm resistance, 10 volts

will pass 10 amperes. The loss in watts being the product of the number of volts and amperes, 10×10 or 100, which is the number of watts used in such a conductor when 10 amperes are passing. If 20 amperes were then passed through the same conductor we would find that it took 20 volts pressure to put it through. The watts used being now 20×20 or 400, or 4 times the power that 10 amperes required.

It has been mentioned that this loss shows itself by heating the conductors and in this connection it must be stated that but a slight rise in temperature can be allowed, on account of the danger from fire at points in buildings where the conductors pass near wood etc. If a conductor is enclosed in an insulating covering, its radiating capacity is reduced, for as a general thing, insulators are poor conductors of heat. Thus, after a great deal of experimenting under various conditions, a table was made, showing the "safe carrying capacity" of copper wires of various sizes. (see table in back of book). The carrying capacity given in this table is that allowed by the Board of Underwriters for wires used for interior work.

We can see that there are two limits between which we must work. The wires must not be allowed to carry more than their safe carrying capacity, in which case we will probably find that the per cent. of loss would be higher than it should be, nor can we increase the size of our conducting wires to any great extent over that absolutely necessary, without making the cost of copper excessive.

The fundamental elements of the case now having been explained, let a practical case be taken. Let the

dynamo D, figure 19, designed to furnish a constant potential current, be connected by wires to 100 incandescent lamps in each of two buildings, 1000 feet distant. The incandescent lamps are to be made to give 16 c. p at 110 volts pressure. The wires from the dynamo to the "centre of distribution" will be called "feeders". The centre of distribution being the point at which the feeders are connected to the "mains."

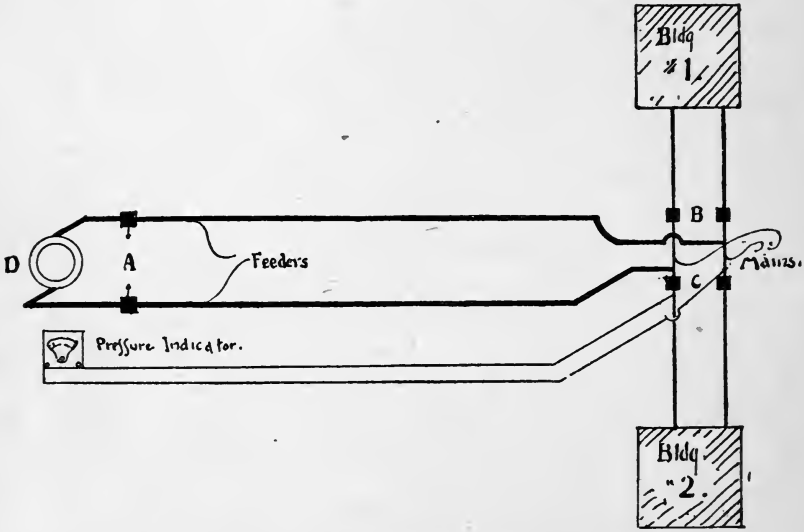


FIGURE 19.—PLAN OF CURRENT DISTRIBUTION SHOWING FEEDERS, MAINS AND PRESSURE WIRES.

When the buildings are reached, the wiring then consists of "mains" and the service wires, or tap circuits from the mains on which the incandescent lamps are placed. Thus the distributing system of such an incan-

descent light plant will consist of feeders, mains and the branch circuits to the lamps to the mains. The aim will be to keep the voltage at the mains, constant and uniform, the pressure in this case being about 112 volts, and thus allowing for about 2 volts loss at full load, between the mains and the lamps themselves. The dynamo will generate a maximum of 125 volts, thus giving a maximum voltage to be used in overcoming the resistance of the "feeders" at full load, the difference between 112 and 125 or about 13 volts, which is about 10% of 125 volts. To show the pressure of the mains which we have shown have a voltage but slightly higher than that used by the lamps, "pressure wires" are usually run back from the mains to "pressure indicators" or voltmeters situated in the dynamo room. Thus at a glance, the dynamo tender can see the exact voltage at the lamps and regulates his dynamo accordingly.

Assuming that this is a practical case, we first desire to know what the size of the wire must be for the feeders to carry current for the 200 lamps with a loss of 13 volts or 10% in the wire. The 16 candle power lamps of 110 volt type, will take practically ½ ampere each. Thus, the dynamos will have to supply 100 amperes for the 200 lamps.

The formula for calculating the size of the feeder, is

$$\text{C. M.} = \frac{21.21\ \text{C D}}{\text{E}}$$

C. M.=Area in Circular Mils.

21.21=Resistance of 2 feet of copper 1 mil in diameter.

C=Current in amperes.

D=Distance in feet, to the lamps.

E=Loss in volts in the wire.
In the case given, C=100, D=1000 and E=13.
Thus the size of the wire in circular mils or C. M. is

$$\frac{21.21 \times 100 \times 1000}{13} = 163,153$$

Thus the wire must have a sectional area of 163,153 circular mils to carry the 100 amperes, 1000 feet, with a loss pressure of 13 volts. By consulting the table of wire in sizes in the back of the book, it will be seen that the nearest size, is No. 000 B. & S., which has an area of 167,800 C. M. The diameter in mils or thousandths of an inch of such a wire is 409.6. Thus it is seen that to maintain a pressure of 112 volts at the buildings 1000 feet from the dynamo, when the 200 lamps are burning, will require a No. 000 B. & S. wire.

We have shown the buildings 1 and 2 to be 200 feet apart, and as before stated, it is desirable to make the loss in the mains as low as possible; in this case for example, 1 volt. What size wire must be used? We will use the formula used in the first case,

$$\text{C. M.} = \frac{21.21 \text{ C D}}{\text{E}}$$

there will be a current of 50 amperes in either branch from the centre of distribution to the buildings. Thus in the formula, C=50 amperes, D=100 feet and E=1 foot, thus:

$$\frac{21.21 \times 50 \times 100}{1} = \text{C. M. or } 106,050$$

which is slightly larger than a No. 0 B. S. wire, which has an area of 105,592 C. M. We now have our

wire sizes to deliver current inside the buildings at 111 volts, which leaves one volt to be expended in overcoming the resistance of the service wires, from the mains to the lamps themselves. This loss is calculated in the same manner as the other two cases. We may in this calculate the size wire necessary to deliver any number amperes any distance at any loss and the formula should be remembered by anyone having any distributing work to do, as it makes him entirely independent of wiring tables, since he has the key to the whole plan himself.

In all constant potential distributions, safety devices must be so placed in the conducting wires, as to make it impossible to overload the dynamo or wiring by an extra flow of current, due to metallic contact between the wires, accidentally or otherwise and thus produce what is known as a "short circuit". Short circuits may be caused by two wires having a difference of pressure coming in contact with each other or with any other conductor, so as to cause an excessive flow of current which may overload the dynamos or perhaps melt the conducting wires unless a safety device is so placed as to cut off the current until the trouble is remedied. On the usual constant potential circuits used for lighting "fuses", made of an alloy having a low melting point, are placed in the circuit, so as to melt when an excessive amount of current pass through them and thus open the circuit. In figure 19, fuses at A. B. and C. are so placed as to protect the wiring, as shown. The fuses at A. would be of such size, as would carry 100 amperes safely, but any excessive amount above this, would speedily heat the fuses to their melting point and the circuit would then be "open". At B and C the fuses would be

of 50 amperes carrying capacity and any rise above 50 amperes would melt the fuse and protect the wiring beyond it. It should be understood that fuses are used simply to prevent more current to pass through a wire than its safe carrying capacity allows, and whenever placed should be so arranged as to size as to open the circuit before the wire is carrying more than its safe carrying capacity. They must melt before the smallest wire which they protect, shall have passing through it, more current than the law allows. Fuses even at their best, are often sluggish in operating, especially when of large size, and great care must always be exercised in putting the proper fuse in the proper place.

For places where an unusually heavy fuse would have to be placed, such as the dynamo room of a street railway plant, instead of fuses, "circuit breakers" are often placed, which open the circuit by mechanical means and they are undoubtedly far more reliable and satisfactory than any system fuses could be. The usual plan of operating mechanical circuit breakers, is to have a magnet carrying the whole current of the wire it protects, so arranged as to trip a catch when the maximum current is reached, and this catch releases the contacts, which separate and thus open the circuit.

The loss of electrical energy in a conductor of a given resistance varies with the square of the current in amperes passing through it. If a certain wire has for instance, 5 ohms resistance, it will take 10 volts pressure to put 2 amperes through it, the loss in watts being 2×10 or 20. If we pass 4 amperes through this same wire it will take 20 volts, the watts being now 4×20 or 80, thus in doubling the current in a given wire, the loss in watts

will be increased 4 times or as before stated, it varies with the square of the current.

For the reason that the loss in a conductor varies with the square of the current in amperes passing through it, it has always been the aim of electrical engineers and inventors to make lamps, motors, etc., operate at as high a voltage as is permissable with due regard to safety and reliability. Up to the present time incandescent lamps

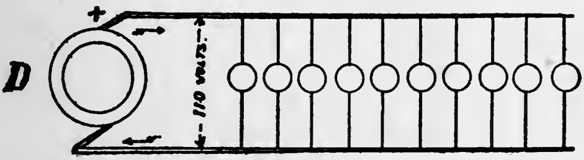


FIGURE 20.—SIMPLE MULTIPLE SYSTEM, DYNAMO SUPPLYING 10 LAMPS.

have not been made so as to give good results at any higher voltage than about 110 volts and for this reason we are practically limited to 110 volts pressure as the highest to be used for the operating of incandescent lamps when placed in multiple.

The Edison 3 wire system was designed to make it possible to carry current a much greater distance from the dynamo than was possible by the simple multiple system without great loss, and by its use the loss can be greatly reduced in a system of distributing current for lighting. The amounts of copper necessary to distribute current for a certain number of lamps, by the 3 wire system is about 3/8 of that used in the simple multiple system.

The explanation of the plan of wiring will be shown in

the figures 20, 21, 22 and 23. In Fig. 20, the 110 volt dynamo D, is shown connected to its load of 10 incandescent lamps. The current flows out from the positive brush and then through the lamps back to the negative

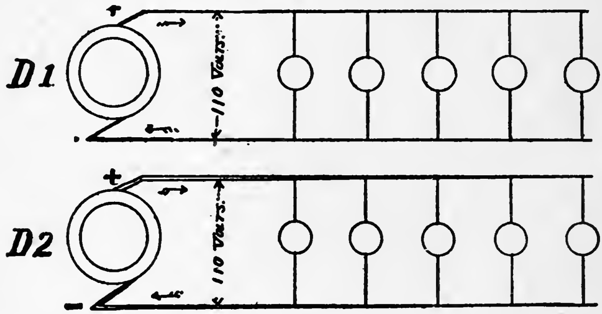


FIGURE 21 —TWO DYNAMOS SUPPLYING 5 LAMPS EACH, ON MULTIPLE SYSTEM.

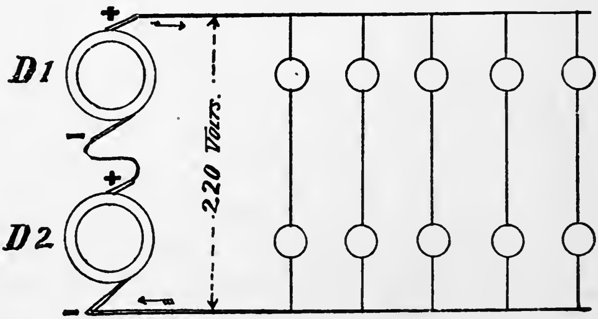


FIGURE 22.—MULTIPLE SERIES SYSTEM FOR 10 LAMPS.

brush; assuming that each lamp is 32 candle power at 110 volts pressure, it will take one ampere of current, thus the 10 lamps take 10 amperes of current. This plan

as shown in Fig. 20 is a simple multiple plan of wiring Fig. 21 shows the same number of lamps but they are supplied by two dynamos D1, D2, each of half the capacity in amperes but the same voltage as dynamoD in Fig. 20. Thus with the 5 lamps connected to each dynamo, there will be 5 amperes flowing out from the positive brush and through the lamps back to the negative brush of each dynamo. Now, if the two dynamos D1 and D2, were connected in series and each of them was designed to generate 110 volts it is evident

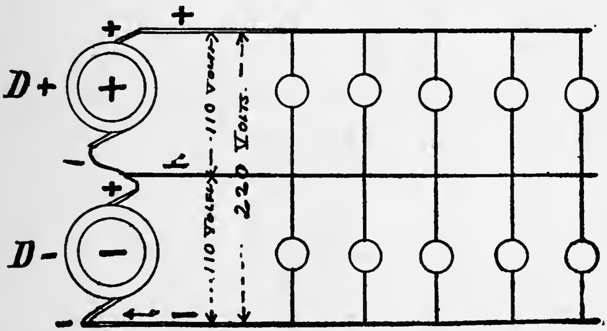


FIGURE 23.—EDISON 3 WIRE SYSTEM SUPPLYING 10 LAMPS.

that the 110 volt lamps may be connected in series of two and give their proper candle power as shown in Fig. 22. The current flowing out from the positive brush of D1 will be but 5 amperes, for there are now 5 series of 2 lamps each, each series taking 1 ampere at 220 volts pressure.

This plan would not meet practical conditions, for if one lamp of a series of two were turned out, its mate

would also be extinguished. A single lamp could not be turned on and off at will and to make it possible to do so, a third wire must be added, Fig. 23, which will make it an Edison 3 wire system. In this case D+ and D— represent the dynamos D1 and D2 in figure 21 & 22. The 3 wires are marked +, ± and —, and are called respectively, positive, neutral and negative wires. The two dynamos are connected in series as in figure 22, and the pressure between the two outside wires + and —, is therefore 220 volts. The pressure of each dynamo being 110 volts, there must be but 110 volts pressure between the + and the ±, or between the ± and — wires. The current flowing out from the + brush of the dynamo D+ must be but 5 amperes and as long as the loads in amperes are equal on both "sides" of the system there will be no current flowing in or out on the middle or ± wire. If, however, a lamp is turned off on the "positive side" of the system, (the lamps supplied by D+) the current flowing out on the + wire will be but 4 amperes, which will destroy the balance and we will then find a current of one ampere flowing out on the neutral wire to make up the 5 amperes needed for the "negative side" of the system. The current flowing on the neutral wire will be the difference between the loads in amperes on the two sides of the 3 wire system. If the loads in amperes on the two sides balance, the station switch on the neutral wire can be opened and the lamps will not be affected. With the neutral switch closed, it is evident that by opening station switch on the positive wire, that all the lamps on the + side will be put out, but that the lamps on the — side will burn as usual and if the station switch on the negative wire is opened and the positive and neu-

tral switches closed, the + side will burn and the — side be put out.

As to the saving in copper and relative losses in this system as compared to the simple multiple system, it will be noticed that the outside wires carry but half the number of amperes that would be necessary on the multiple system, figure 20, and that the middle or neutral wire usually carries but a small amount as compared to the outside wires. Thus, if for a moment we ignore the necessity for a neutral wire, the size necessary for the 2 outside wires will be found to be but ¼ the size necessary to supply current for the same number of lamps, the same distance from the dynamos, in a simple multiple system of distribution, for the current at 220 volts is but 5 amperes, and the loss is twice as many volts, for if we assume a loss of 2 volts from the dynamo to lamps on the simple multiple system, the dynamo voltage must be 112 volts and the voltage at the lamp is 110. Thus in the 3 wire system with each dynamo generating 112 volts, we will have 224 volts between the outside wires at the dynamo and since the two 110 volt lamps in series need but 220 volts, it will be seen that we can allow a 4 volt loss in our wiring and still have the lamps up to candle power. Thus it will be seen that our loss in volts is 4 instead of 2 and our current in amperes is reduced from 10 to 5, thus, each of our outside wires need but be ¼ the size that would be necessary for the same number of lamps on a simple multiple distribution.

As has been stated the middle or neutral wire should carry but a very small amount of current in a well designed 3 wire system, but for the reason that the fuses on either of the outside wires might be melted in case of a

short circuit and thus make the middle wire carry as much as the outside wire, the rule has been followed, of making the neutral or middle wire as large as either of the inside wires, thus we have 3 wires, each $\frac{1}{4}$ the size that would have been necessary for each wire of a simple multiple system and the relative amounts of copper will thus be $3\times\frac{1}{4}=\frac{3}{4}$ for 3 wire or $2\times 1=2$, the size for simple multiple wiring, the relations are thus: $\frac{3}{4}$ to 2 or $\frac{3}{8}$ to 1.

In calculating wiring for 3 wire distributions we may get the size necessary for a simple multiple system of wiring for the number of lamps we desire to run on the 3 wire system and then divide the area of the wire in circular mils needed for each of the wires of the multiple system by 4, which will give the area of the size wires needed to distribute current to the same number of lamps by means of the 3 wire system.

The Edison 3 wire system is used by nearly all the larger size stations supplying direct current for incandescent lighting.

There are 4 and 5 wire systems sometimes used, which are operated on the same plan as 3 wire systems with the exception that an extra dynamo is used for each additional wire, thus a 5 wire system will have 4 dynamos, or their equivalent, all working on the same lighting system. It is doubtful if the extra complication necessary with such a system is in the line of economy or not, especially with medium sized plants..

For supplying current to street car motors, a plan of current distribution is used, which in the usual single trolley systems is very different from that used to supply current for illumination.

The usual method employed will be readily understood from figure 24. The dynamo D of the compound wound constant potential type is designed to generate a varying amount of current at about 500 volts pressure. The positive brush is connected to the trolley line L and the negative brush should be connected to the rail or to the copper wires laid in the ground near the track, which serve as the return circuit for the current. Thus the negative side is always "grounded" and in fact, the earth itself is used to a limited extent for the return circuit of the current used in operating the motors on the cars. In most cases it has been found that the earth cannot be

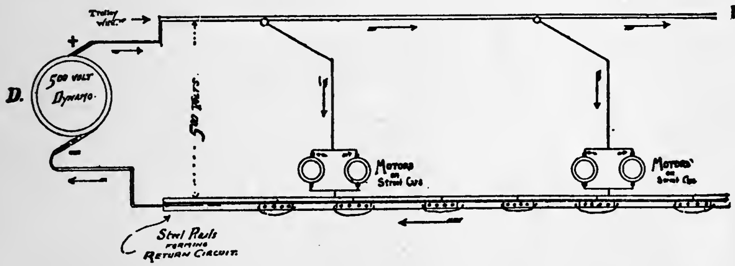


FIGURE 24 —STREET RAILWAY TROLLEY SYSTEM.

depended on to furnish a path of low enough resistance to insure satisfactory results and a system of "bonding" is always resorted to. The "bonding" consists of uniting the ends of the rails together by means of heavy copper "bond wire" thus making use of the metal section of the rail to form a continuous metallic circuit from the cars back to the power house. The question of a good return circuit that is durable, is one that has worried the de-

signers of electric street railways a great deal. This is owing to electrolytic action on the rails, bond wires or on water and gas pipes or other metal conductors near the line of electric road. If a current of electricity be made to flow from or to a metal plate immersed in a conducting fluid, an electro-chemical action is set up which disintegrates or destroys the metal, the rate depending on the amount of current flowing. This same action is taking place on the rails and other metal conductors when they are placed in moist earth, and its destructive action will depend on the amount of current flowing from the metal to the earth. In an electric street railway track, if the rail circuit contains considerable resistance, part of the current will flow to the earth from the rail, and if water pipes or other good electrical conductors in the earth are in such a position as to make a part of the return circuit, current will be conducted through them, and the chemical action set upon the metal surfaces will rapidly destroy them and make great trouble. The only way to obviate this trouble is to make the return circuit through the track so good that there will be but little current flowing from the rail to the ground, for the current will always divide depending on the relative resistance of the paths offered it.

There are some cases of distribution of street railway current by means of two trolley wires, one of which is connected to the positive brush and the other to the negative. In this case the earth and rails do not form a return circuit, the entire distribution being effected by means of the two trolley wires, between which 500 volts pressure is maintained. The motors are of course connected between the two wires, by means of two trolleys,

which bear against the trolley wires and thus make contact with them.

Underground conduit distribution for street railways is gradually being developed, and in some cases we will find the rail being used as a return circuit and in others two underground trolley wires are used, insulated from each other and from the earth, in which case the conducting wire of course have no more connection with the rail as a return circuit than the double trolley system of overhead distribution, does with the track circuit.

CHAPTER V.

TRANSFORMERS AND ALTERNATING CURRENT DISTRIBUTION.

In the preceding chapter, we have not spoken of alternating current distribution and have purposely avoided doing so for the reason that there are several peculiar characteristics of pulsating and alternating currents which should be thoroughly studied by themselves.

By suddenly completing and then breaking an electric circuit, it will be found that there seems to be an action take place, similar to that of inertia. The current does not rise instantly rise to its full value and when the circuit is broken, there will be evidence of the current tending to resist the breaking of the circuit. This effect varies with the "inductance" of the circuit. The inductance being the magnetism producing effect of the circuit.

If the circuit is through a coil wound on an iron core, the effect will be much greater than if the wire is not wound in coil form.

This action is caused by the lines of magnetism or the magnetic field being generated around the wire when the current is started through it. Each wire has its magnetic influence which is created the instant that the current starts flowing through it. If this wire is part of a coil, its magnetic influence must affect other neighboring wires of the same coil. The effect will always be

such as to retard the flow of current through such a coil, until the full current strength is reached. The "self-induction" as it is called, will vary with the square of the number of turns in the coil. Thus, a coil of 10 turns has 100 times the self induction which a coil of one turn would have. If, then, we connect the terminals of a large coil of wire which surrounds an iron core, to a source of electricity, we will find that it takes an appreciable time for the current to reach its full strength, and that when the terminals are disconnected, that a spark will show itself in breaking the contact which is many times larger than it would have been, in case the same amount of current was interrupted, which had not passed through a coil such as described. The self-induction of a circuit, always resists the sudden starting and stopping of a flow of current. This effect may be very easily demonstrated by placing an ammeter in series with a field magnet circuit of a shunt wound dynamo and watching the gradual rise in current through the circuit, on connecting it to a source of electricity. On a "dead beat" ammeter, that is, an ammeter whose needle comes instantly to the correct reading, without going past it, the gradual rise can be readily seen, and on breaking the field magnet circuit, a flash will take place which clearly shows that the current resists being broken. In fact, the voltage at the terminals of a 110 volt dynamo field coil circuit, may be several times 110 volts the instant the circuit is broken and a shock obtained in this manner is often exceedingly painful, if not dangerous.

It will now be evident that when a current of electricity is started through a coil of wire, that each wire is sending out its magnetic influence, which may effect other

conductors in its vicinity and in fact, if two coils of wire are placed near each other so that the magnetic influence of one coil may affect the other, it will be found that the instant current is started in one coil that a current will at once be generated in the second coil, the amount generated depending on the resistance, etc., of the second coil. It will be found that the current in the second coil

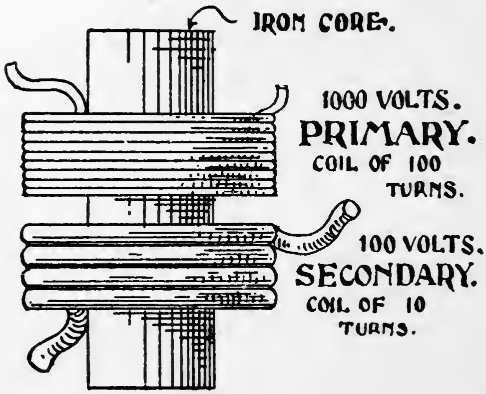


FIGURE 25.—IRON CORE WITH PRIMARY AND SECONDARY COILS.

will only be generated while the current in the first coil is being increased or diminished and that the instant that the current in the first coil becomes a constant quantity that the current in the second coil falls to zero. Also that the current in the second coil flows in one direction during the *rise* of current in the first coil and that the current flows in an opposite direction when the current in the first coil *diminishes* in

strength. Thus by sending a pulsating or alternating current through the first or *primary* coil, a pulsating or alternating current may be generated in a second or secondary *coil*, although there is absolutely no metallic connection between them. See figure 25.

Alternating current dynamos are easier to build than pulsating direct current dynamos, and are certainly easier to handle. They have no commutator, but instead have collecting rings which are the terminals of the coils on the armature. Brushes bear on these rings and in this manner connect the armature coils to the wiring connected to the lamps, The usual alternating current dynamos used for lighting purposes, give out from 15,000 to 16,000 alternations per minute, although dynamos lately constructed are being made from 6,000 to 9,000 alternations per minute, which is in the line of foreign practice. The usual alternating current dynamo is designed to generate either 1,000 or 2,000 volts and a varying number of amperes, and this pressure is reduced at a *transformer*, to 50 or 100 volts for use in operating the usual incandescent lamp.

The electro-motive force or voltage generated in the secondary coil, as compared to the voltage on the primary, will depend on the relative number of turns in the two coils. If the primary coil is connected to 1000 volts pressure of alternating current and has 100 turns in it, we will have generated in a secondary coil of 10 turns, a pressure of 100 volts, or if there are but 5 turns of wire in the secondary coil, we will have but 50 volts between its ends. We can in this manner generate alternating currents of high voltage and distribute them long distances from the dynamos, with a small loss and when the build-

ing is reached which is to be lighted, the high pressure current is connected to the primary coil of a *transformer*, on the secondary coil of which the lamps are connected. If there is 1 ampere at 1000 volts or 1000 watts passed through the primary coil, we will find practically the same number of watts given out by the secondary coils, the only change being that at 100 volts we will have a current of 10 amperes or at 50 volts—20 amperes. Thus the current in amperes is increased in proportion to the reduction of pressure and it is possible in this way to generate any voltage desired on the secondary winding, by proportioning the number of turns in the primary and secondary coils. The efficiency of transformers, that is, the proportion of the energy supplied the primary coil given out by the secondary varies in different makes, but at full load, large transformers can be made to give to the secondary from 95% to 97% of the energy supplied the primary.

Figure 26, represents an alternating current dynamo, generating a constant pressure of 1000 volts, connected to 2 transformers, 1 of which (No. 1) reduces to 100 volts, the proportion of turns on its primary and secondary coil being 10:1, and the second transformer (No. 2) reducing to 50 volts the proportion of turns in the two coils in this case being 20:1.

The same dynamo may supply a third form of transformer which is called a "step up" transformer, the primary coil being supplied with 1000 volts current and the secondary coil supplying a higher voltage, 5000 volts. This is accomplished by winding a proportionately larger number of turns on the secondary coil than is wound on the primary, the proportion being 1:5.

It must be understood that the secondary coil has no metallic connection with the primary coil, and that whatever current is generated in it, must be due to the inductive effect of the current in the primary circuit. To get the maximum effect of the current in the primary circuit on the secondary winding is the first requisite in a good transformer.

The coils are therefore both placed on an iron core in such a position that as many as possible of the magnetic

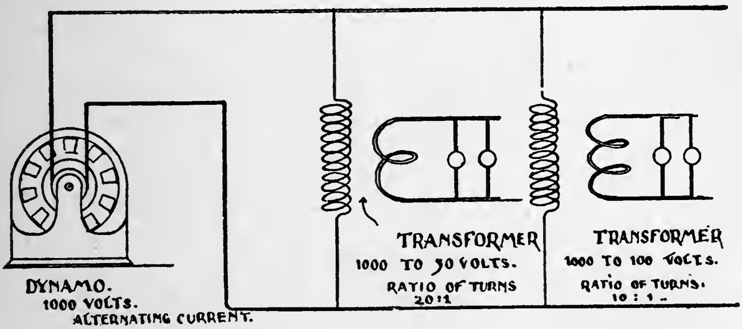


FIGURE 26.—PLAN OF ALTERNATING CURRENT DISTRIBUTION.

lines from the primary coil will embrace the secondary winding. The coils are usually placed close to each other and in fact, would be interlaced with one another, were it not for the fact that aside from difficulty of manufacture, the danger of contact between the high voltage current carried on the primary circuit and the lamp circuits from the secondary windings would prohibit it. In practice we will find that the primary coil is extremely

well insulated from its neighboring secondary coil, so as to make it quite unlikely for contact between them.

The theory of the transformer is quite complex when all of its internal actions are taken into consideration and many books have been written, filled with algebraic formulas in regard to the transformer and its actions.

We may take up a few simple actions however, without the aid of mathematics. We have already spoken of self-

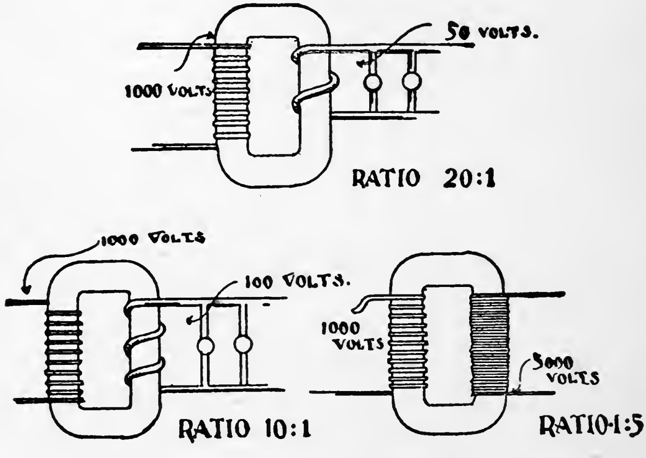


FIGURE 27.—FORMS OF TRANSFORMERS.

induction of a coil of wire surrounding an iron core, and have shown that it takes an appreciable time for current to reach its maximum in a coil having self-induction. Also the apparent resistance offered to the breaking of the circuit. If an alternating current be supplied to a coil surrounding an iron core, we will find that owing to the self-induction of the coil, it will be impossible to pass

as much current through it with a given voltage as would be possible with direct current of the same voltage. In fact, in a coil having for instance, 10 ohms resistance, we might be able to put but $\frac{1}{10}$ ampere through it with a voltage of 1000, provided the coil was wound on an iron core after the manner of a primary coil of a transformer. 1000 volts of direct current would put 100 amperes through the same coil. This difference is due to the self-induction or "impedance" of the coil when supplied with an alternating current. The reason is, that with the current alternating 15,000 or 16,000 times per minute that the electro-motive force or voltage, although high, does not have time to force the current to its maximum, before having fallen to zero and exerted an electro-motive force tending to reverse the current in the coil. The amount of energy expended will be in this case, only a small amount and in a transformer will be termed the *leakage* or *magnetizing current*.

The leakage will depend on several factors. In the first place there must be enough iron in the transformer core to form a path of low magnetic resistance for all the lines of magnetism given out by the primary coil, so that with the secondary coil placed on this core, practically all of the magnetism of the primary current will effect the secondary winding. Great care must be taken in selecting the quality of iron, for the magnetism of the iron transformer core is being reversed each alternation of the current and some kinds of iron will magnetize more quickly than others. It takes power to reverse the magnetism in the iron and this loss is called *hysteresis* loss, hysteresis being the loss occasioned by altering or reversing the magnetism of iron. This hys-

teresis loss is smallest when a soft iron core is used and to provide against *eddy currents* in the core, it is *laminated* in the direction parallel to the lines of magnetism in the core. The eddy currents in a solid iron core would be caused by the magnetic effect from the primary and secondary coils generating currents of electricity in the iron itself, which although of extremely low voltage, would have sufficient current strength to heat the iron and core, thus not only endanger the insulation of the transformer but also counteract part of the magnetic effect in the iron. Thus the cores of transformers and in fact, all coils which carry alternating currents should be divided in small sections either by building them up out of thin sheet iron or out of soft iron wire. These divisions should not be made so as to break the continuity of the magnetic circuit, but must be made parallel to the lines of magnetism in the iron core.

The leakage in the primary coil is of course partly dependent on its resistance, but this resistance has practically no effect at all in the case, we have mentioned of a single coil wound on an iron core for the impedance due to self-induction in the coil, exerts by far the most powerful tendency to keep the current from passing through the coil.

If now, on the laminated core of iron, we place a second coil and for instance, have the ratio of turns of wire in the high pressure as compared to the low pressure or second coil, 10 to 1, we will find that when the primary coil is connected to a 1000 volt constant potential alternating current circuit, that the low pressure coil forming the secondary winding will have a voltage of 100 volts at its terminals and if we have a correctly designed trans-

former of say, 5000 watts capacity (100—16 c. p. lamps) will find that with practically no current in the secondary circuit, that there will be a leakage on the primary of about $\frac{1}{10}$ ampere at 1000 volts pressure. If now, 10 lamps each taking ½ ampere at 100 volts are connected to the secondary winding, we will find that the current in the secondary circuit will now be 5 amperes and that the primary current has increased from $\frac{1}{10}$ ampere to $\frac{6}{10}$. If 10 more lamps are now connected to the secondary, the primary current will be found to be $1\frac{1}{10}$ ampere. In fact, as the current in the secondary winding is increased, the primary current is also increased and this increase in the primary should be as many watts as is added to the secondary load. The self-induction and impedance of the primary circuit is being *decreased* by the *mutual induction* taking place between the secondary and primary windings, for as the load increases in the secondary winding, just so much is the counteracting effect of the secondary winding on the primary. Thus owing to the decreased impedance of the primary coil, owing to the effect of the current in the secondary winding more and more current flows through the primary coil, until at full load the primary winding is carrying its maximum current and the secondary is exerting its full contracting effect on the impedance of the primary winding. The efficiency of such a transformer should be about 97% at full load. That is, the secondary winding should be delivering 97% of the energy supplied to the primary coil.

Thus it will be seen that alternating current can be distributed at high pressures and then reduced at transformers to a voltage suitable for operating incandescent

lamps with but a small loss in transformation. The loss in watts in transmitting a certain amount of electricity through a wire of given resistance may be stated as varying with the square of the pressure or voltage at which it is transmitted.

Thus to deliver 5000 watts, 1 mile from the dynamo at 1000 volts pressure, will take $\frac{1}{100}$ as much copper as that necessary to send the same 5000 watts at 100 volts pressure with the same loss. For several reasons, 1000 or at most, 2000 volts pressure is as high as is safe to go in generating current for ordinary lighting plants and most alternating current dynamos are made for either one or the other voltage.

In most large alternating current stations the highest voltage generated is about 6,600 volts which is either stepped up to any voltage from 6,600 to 150,000 volts or stepped down. In many cases it is consumed as it is generated.

A transformer may have more than one secondary coil or a single coil may be divided into two or more sections and by varying these connections, it will be possible to get for instance, from the usual form of transformer used in America for incandescent lighting, 50 or 100 volts as desired by connecting the two sections of the secondary in multiple or series with each other. Fuses are usually placed on the primary wires only, in the modern type of transformer. In case of a short circuit in the secondary winding or the wires leading from it, the primary fuse would immediately be melted, and thus open the circuit. When the secondary wires enter buildings the usual method of fusing all circuits must be carried out, not as a protection to the transformer, but as a protection to the smaller tap wires leading to lamps, etc., which unless

provided with fuse wires might in case of a short circuit, melt before the primary transformer fuse would open the circuit.

The wiring from the transformers to the lamp should be carefully calculated, owing to the fact that the transformers on a constant potential primary circuit cannot provide extra pressure as the load increases so as to compensate for loss in the wiring. The wiring on all secondary circuits should be done so as to provide for a very small drop, for in fact, the secondary voltage gradually falls as the load increases and although in the well designed transformers, this drop amounts to but from 1% to 2%, it is oftentimes sufficient, when combined with loss in the secondary circuit, to cause a marked diminuation in candle power of the lamps.

Special transformers are often wound so as to give from 30 to 35 volts on the secondary winding, which is the voltage needed to operate the usual type of alternating current arc lamps now on the market.

Step up transformers are usually used in places where it is desired to send electricity for lighting, etc., a considerable distance from the dynamo. The voltage of the alternating current dynamo or "alternator" is usually 1000 or 2000 and this is raised in the step up transformers to pressure sometimes as high as 150,000 volts. The current at this pressure is then transmitted in some cases twenty or even one hundred miles and then the pressure is again reduced to that desired for lighting, etc.

The usual alternating current dynamo as used for lighting, supplies a *single phase* current as distinguished from alternating current dynamos supplying *multiphase* currents, which may have *two*, *three* or more *phases*.

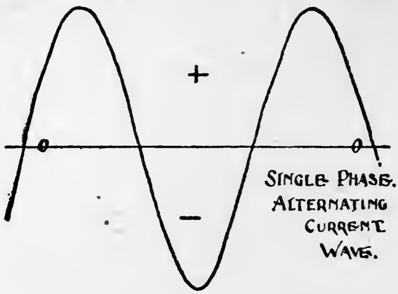


FIGURE 28.—PLAN A.

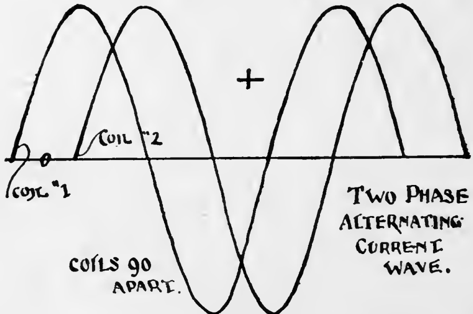


FIGURE 28.—PLAN B.

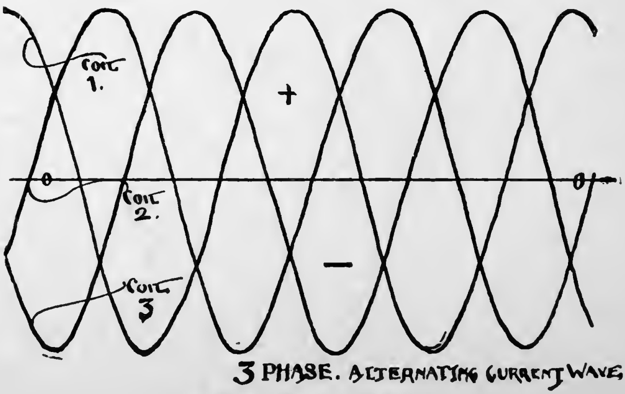


FIGURE 28.—PLAN C.

A dynamo which supplies an alternating current which consists of a succession of single alternating impulses will be called a single phase dynamo and such a current is a single phase current.

If, however, there are two windings or their equivalent on the armature, each of which is sending out a single phase alternating current, the dynamo is now a two-phase dynamo and by designing the armature coils so that the rise of current in one armature winding is not coincident with the rise in the other winding, peculiar magnetic effects may be produced in a suitable form of magnet by providing it with two windings, which are supplied with current from the two armature windings of the two phase dynamos. Likewise, three windings may be placed on a single armature and thus make a three-phase dynamo generating a three-phase current. The figures 28 show the current wave of a single phase alternating current dynamo (plan a). Plan b, shows a two-phase current, in which the relative amounts of current during a revolution are shown in the two windings. The waves of current in this case are in quadranture, that is, one coil's current wave is 90° ahead of the current in the other coil. Plan c, shows the relations of the currents in the coils of a three-phase generator. The currents are in this case 120° ahead of each other.

CHAPTER VI.

TYPES OF DIRECT AND ALTERNATING CURRENT DYNAMOS.

Direct current dynamos are manufactured principally in three types, shunt, series and compound wound.

The shunt dynamo is found largely in isolated and central station electric lighting plants, operated on the two and three wire systems, and supplying incandescent lamps, small electric motors and constant potential arc lamps.

These three types of machines are made in bipolar (two poles) and multipolar (more than two poles) design as respects field magnets.

In the previous chapters, the reader has learned that a current is generated in the armature by the movement of coils of wire in a magnetic field which is usually produced by electric currents flowing through coils encircling bodies of iron, called field magnets, and that the electric currents generated in the armature are taken from it by means of the commutator and brushes bearing on it.

Consider a U shaped piece of iron forming the field magnet, wound with wire so as to form an electro-magnet when supplied with the electric current. Now in the shunt dynamo, the two terminal wires of a magnet similar to this are attached to the armature terminals

and form a shunt around the armature from whence the name "shunt dynamo" is derived.

By previous application of an electric current to the coils surrounding the iron cores, they have been magnetized and iron once magnetized always retains a little of its magnetism, called "residual magnetism". If then, there is the feeble magnetism remaining in the magnet, it follows there must always be a slight magnetic field between the poles of the field magnets and as there is an armature revolving in that field, a current is generated which passes out to the commutator and by brushes is led off to the circuit. One path which this current can take is that through these field coils which at once causes them to be more powerfully magnetized and a greater magnetic field is thus produced, hence a greater amount of current is generated in the armature. By this step by step process, the machine slowly "builds up" to the proper potential until the normal magnetization is reached.

A rheostat or a variable regulating resistance is in series with and connected in the field circuit which regulates the potential or voltage by varying the current through the fields. When a dynamo is running with no load, all the resistance in the rheostat is generally in circuit. Now as the load increases, whether it be that electric lights are switched on or motors are run, either of these will require dynamo current and the potential of the armature falls slightly. To get more current in the fields so as to raise the potential, we must increase the current through them by manipulating the rheostat. A shunt or compound wound dynamo generally speaking, has its pressure remain constant and the current quantity varies

as more or less lamps are turned on. The shunt or compound wound dynamo for supplying constant potential current usually depends on the varying strength of the field magnets for regulation, but the series wound dynamo supplying a constant current is often regulated by "armature reaction" alone, the armature reaction being the internal electrical action of the armature windings, which may be used for regulating.

The series dynamo is used almost exclusively for series arc lamps, but series motors can be placed on the series dynamo, and operated. The field magnets are in series with the armature and full current of armature must pass through them. Again we find that the series dynamo usually generates a variable pressure and constant current. Arc lamps are run in series with the dynamo, and if this current supplying them fluctuated, as does that on a shunt machine it would produce great variations in the candle power of the lamps which would make a very unsatisfactory light. The arc lamp when burning on a ten ampere circuit has a resistance between the carbons of 4½ to 5 ohms and to force the requisite 10 amperes of current through the arc, a pressure from 45 to 50 volts ($C \times R = E$) is required. If 10 lamps are to be run, the dynamo must supply the 10 amperes at a pressure of 500 volts and the dynamo for this purpose usually has its brushes shifted so as to cut in additional active coils in the armature, which means an increase in pressure or voltage on the line for the extra lamps cut in the circuit. No rheostat is necessary in this case, as the regulation of the armature by the shifting of the brushes keeps the current constant through the fields, the magnetic field of the dynamo always containing the same number of mag-

netic lines. In the series wound machine the brushes are shifted against the direction of rotation for an increase of load.

The compound wound dynamo supplying constant potential current, though embodying the shunt and the series principles, is more a shunt machine than series. Its regulation depends upon its fields. Its voltage is constant and ampereage variable. In a well designed dynamo after the voltage is regulated by means of the rheostat, the machine takes care of itself. The armature rotates in a powerful magnetic field. In either the shunt or compound wound dynamo, it is possible to so proportion the field magnets and armature that the "non-sparking" point on the commutator is not shifting as the load varies, although in many makes of dynamos, as the load increases the brushes must be shifted forward in the direction of rotation, or sparking will result. This is caused by the magnetic effect of the armature distorting the flow of magnetic lines given out by the field magnets so as to alter the position of the neutral line in the armature. In compound wound dynamos all the current generated in the armature passes through the series windings on the fieldmagnets. The machines are so built that the series winding does the regulating and the magnetic field does not reach its full strength until the dynamo is delivering its full current. The dynamo "builds up" by virtue of its shunt winding and as current is required from the dynamo for the outside circuits, this same current passes around the series coil of the field magnets, increasing the magnetic field and consequently maintaining the pressure uniform. Compound wound dynamos may be compounded for any percentage increase in pressure from no

load to full load, thus compensating for the "drop" in voltage that occurs on the line when large currents are being passed through them.

Alternating current dynamos consist principally of three classes, self excited, separately excited and composite or compound. They are almost invariably high voltage machines, from 1000 volts up and consist in an armature of as many coils in series as there are field magnets and these are much in excess of those on direct current dynamos. A great number of alterations of the current are required for practical work and consequently to keep the armature speed down to a reasonable point, a greater number of magnet poles are used. Currents generated by the armature are led out in two wires to collector rings, where by brushes connected to the circuit the current is taken to the transformers, etc. The magnetic field extends from one field magnet to its neighbor on either side of it. The field magnets which are usually wound in opposite directions on each successive pole, are excited in the self excited machine by taking the current of one or more of the armature coils and passing it through a current rectifier. It would be useless to excite the fields by the alternating current as the rapid reversals in the current unfit it for such service. The alternating current must be commuted to a direct current and the rectifier or two part commutator performs this function, by sending all the impulses through the field magnets in one direction and they are thus excited by a pulsating direct current. The residual magnetism in this case plays a part in the alternating dynamo as it does in the direct. As the armature rotates in the magnetic field, weak alternating currents are generated passing through the rectifier,

thence around the field magnets, again developing greater currents in the armature until normal magnetism is reached. The separately excited alternator is devoid of a rectifier and has its fields excited by an independent direct current dynamo. Regulation is obtained by varying the current in the field magnets as the load varies by means of a rheostat in the circuit of the direct current dynamo.

The composite field or compound alternating dynamo is analogous to the compound direct current dynamo, inasmuch as an additional winding passes around the field magnets in addition to the usual winding found on the separately excited alternating current dynamos. This winding is supplied with a pulsating direct current from a rectifier which commutes a portion of the output of armature current, the amount depending on the load in amperes. As the current is increased on the circuit, just so is the current increased in the fields and the potential is gradually increased to overcome the "feeder loss." A resistance is bridged or shunted across the rectifier which can be varied so as to produce different increases in the pressure at full load to allow for "drop" in line.

Other classifications of alternators are made, namely: dynamos in which the field magnets are stationary and armature rotates, dynamos in which the armature is stationary and field magnets rotate and those in which field magnets and armature are stationary and an irregularly shaped iron inductor rotates between the two. The principal of the "inductor" type of alternating current dynamo is that if the number of lines of magnetism is varied through the stationary armature coil that the same effect will be produced as when the armature coil

moves so as to cut these lines of magnetism. The revolving iron "inductor" is so shaped that as it revolves it completes and then breaks the magnetic circuit through the armature coil and this of course must generate current in it. Alternating current dynamos are built for any phase and frequency but it is not timely to lead the reader further than has been gone into in the preceding chapter, as other books cover this advanced work.

It is frequently the case that one dynamo is insufficient to supply the circuits that it is feeding at certain hours during the run and it becomes necessary to place an additional dynamo on the circuit. In incandescent lighting, the machines would be placed in multiple, but in arc lighting they would be connected in series. In the shunt wound dynamo an increase in load means an increase in amperes output with voltage constant, while in the series dynamo an increase in voltage results with the current constant. Therefore, if it is required to run an extra machine on a circuit, if it be a shunt or compound of the constant potential type, it is connected in multiple, but if the usual series dynamo, it is put in series. Instances where series dynamos are run in multiple or compound wound dynamos in series are few but explanation will be given their operation.

SHUNT WOUND DYNAMOS IN MULTIPLE.

The directions to be followed in placing shunt dynamos in multiple is as follows:

One dynamo already running—Start second dynamo up to full speed—Set brushes on commutator—Move rheostat handle until voltage of dynamo is the same or slightly greater than that of dynamo already running.

This can be indicated by a voltmeter. A pilot lamp is usually placed on shunt or compound dynamos and they will roughly indicate when dynamos can be placed in circuit. As soon as switch is thrown connecting both dynamos to the circuit, the load should be equalized on each by cutting in resistance in field circuit on the dynamo first running and cutting out resistance on dynamo just switched in. If the voltage of the second dynamo be less than that on the circuit, the dynamo will receive current from the first and operate as a motor turning in the direction of its previous rotation. In taking a machine from the circuit proceed in reverse step. The Edison three wire systems use shunt and compound dynamos. The two dynamos in this case, the positive dynamo supplying the + side and the negative dynamos supplying the — side, are started up as previously explained.

Being independent of each other and working on separate circuits, no especial precautions are necessary in starting dynamos. The potential should be kept alike on both machines and when possible, the current in amperes should be the same. If one dynamo carries more current than another, that difference existing, is is carried by the ± wire. If, as the load increases, additional dynamos are to be placed in parallel on either side of the system they are placed in, the circuit in the same manner as has been described, one dynamo being in multiple with the + dynamos and the other with the — dynamo. One dynamo may be made to supply a 3 wire system by using a switch that will connect + wire with — wire making the neutral a common return for the two outside wires. This method is not to be recommended

unless the original wiring was designed with this object in view.

Shunt dynamos may be connected in series when long distance transmission is to be accomplished. The field circuits should be connected so as to form one shunt across the dynamos so run in series and they will thus all be excited equally. All machines in this case should be of the same current capacity and each must be able to carry the maximum current on the circuit, or in the case dynamos of various sizes in series, the current must never rise above the carrying capacity of the smallest armature in curcuit.

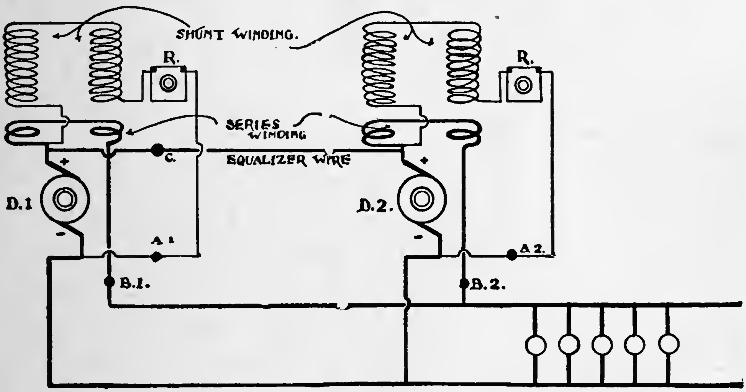
SERIES DYNAMOS IN SERIES.

Dynamos to be thus connected must have same current capacities and the + terminal of one must be connected to the — terminal of the other. In a lighting plant, this is readily performed at the switchboard by plug connectors. This not so satisfactory as making other combinations but is often done. If series dynamos are to be connected in multiple, let the armature of one dynamo excite the fields of the other and vice versa, so that if one generates not enough current, it weakens the field of the others and both are equalized.

COMPOUND DYNAMOS IN MULTIPLE.

The compound dynamo embracing the characteristics of the shunt and series machine, the coupling together becomes an operation including both. In figure 29 two generators are connected for multiple working. One machine is running and the switches A1 for shunt circuit and B1 for series circuit are closed. The armature D1 is then generating its normal electro-motive force and cur-

rents are flowing in the shunt field and the series field circuits. Armature D2 is then run at its normal speed, the switch A2 is thrown, allowing the shunt winding to excite the fields of dynamo D2. The switch C on the equalizer wire is closed and when switch B2 is closed, the machine takes its part ot the load. Before the sec-



CONNECTIONS OF TWO COMPOUND DYNAMOS IN MULTIPLE.

ond dynamo is coupled in circuit, that is, before switch B2 is closed, the voltage should be about the same as that of the dynamo D1 first running. After the two are coupled in circuit, the load on each machine should be balanced by the rheostat. By examining the diagram of circuits, it will be seen that the equalizer wire practically places the two series windings in multiple, and this is necessary, owing to the fact, that in case two compound dynamos in multiple were feeding a circuit and were not provided with an equalizing wire, and one dynamo had its voltage slightly decreased from any cause, for instance a slipping belt, that the current in the series coil of the dynamo

whose voltage was lowered, would necessarily be weakened and this of course would still further reduce the voltage of the dynamo in trouble. But in the case of the dynamos provided with an equalizing wire, the two coils being in multiple and of equal resistance, will have the total current output of the two dynamos divide equally between them and thus tend to keep the two dynamos balanced. The equalizer should have a very low resistance compared to the series windings so as to perform its office satisfactory. In cutting out a machine the same steps are taken only in reverse order. Compound dynamos of different current capacities can be run in multiple, if the voltage is the same and the resistance of the series windings are inversely proportional to the current capacities of the several machines, in other words, if a dynamo produces half as much current as another, its windings should have twice the resistance of the other. The machines also govern each other, as when one machine runs too fast, it does more work and consequently lowers its speed, and momentarily it robs the other machines of part of their load, which makes them run faster and thus producing equality. Compound dynamos may be connected with good results in the manner described under shunt dynamos in series.

ALTERNATORS IN MULTIPLE.

To couple direct current dynamos in multiple we said that their potentials should be alike, but in alternating current dynamos not only this is usually required, but the machines must correspond in phase and frequency. To couple an alternating current dynamo in circuit with another, the impulses in both machines must rise and fall together or be "in step." The frequency, period

and alternations are directly affected by the speed, for the faster the speed the greater the alternations, that is, frequency, and vice-versa. Now when one generator is coupled with another generator or motor and running in step with it, we say they are in synchronism. The instrument provided to indicate synchronism is called a synchronizer and is explained in chapter x. To disconnect alternators when running in parallel, is not as difficult as when coupling in. The main switch of dynamo is opened and then the switch on the exciter circuit to dynamo should be opened. It is a better plan while machines are running on single circuits to reverse this operation, throwing exciter switch first and then machine switch, as there are less chances of injury to alternator. The same effects which cause alternators to work well in parallel causes them to be opposed and get out of step in series.

CHAPTER VII.

CAUSES OF TROUBLE IN DYNAMOS.—THEIR REMEDY AND PREVENTION.

The rotating portion of any dynamo electric machine or motor is its vital part. In some machines, this element is the armature, in others the field magnets. In case the rotating part is the armature, it will be evident that means must be provided to take the current generated from the moving conductors of the armature to the lamps, motors, etc., for which the dynamo is to supply current. This is done usually by means of brushes bearing on the commutator or collector rings, as explained in previous chapters.

The first fault developed in a machine should be speedily removed, and the second fault never allowed to appear, as the machine will rapidly destroy itself.

The following directions apply particularly to direct current dynamos of the "closed coil" type and do not apply to some "open coil" dynamos used for arc lighting. etc.

We have to-day, several different styles of brushes in general use. They come under two general heads, metal brushes and carbon brushes.

Metal brushes are made usually of copper, either of several leaves of thin copper ribbon or a number of copper wires soldered together at one end, or a combination of wire and leaf copper. A patented brush of consider-

able merit is made with leaves of copper arranged between leaves of high resistance metal with a number of sheets of oiled or parafined paper interlaid for lubricating purposes. The idea of high resistance metal either side of the copper, is to stop the sparking by reducing the short circuiting action of the brush on coils that are in the weak field near the neutral point on the commutator.

Carbon brushes are used to a great extent on street railway machinery, both on dynamos and motors. The brushes are cheap, self-lubricating to a great extent, and do not wear the commutators near as much as copper brushes. The sparking which results from rapidly fluctuating loads is not only lessened but is made practically harmless to the commutators, since the burning action of tho sparks seems to concentrate itself on the carbon and does not injure the commutator. For the best results, a good grade of carbon made especially for this purpose, should be used. The vapor of the carbon, generated at a spark, is undoubtedly of higher resistance than the vapor of copper and this must reduce the sparking to a great extent. The carbon brush has been applied to arc dynamos of recent construction with considerable success. On motors which are designed so as to be able to reverse their direction of rotation, such as street car motors, etc., the carbon brush is a necessity and is usually set at right angle to the face of the commutator.

Brushes should have more than sufficient cross section to enable full current of armature to be delivered through them continuously without undue heating, and the cross section of armature segments should be governed by the same rule. Every part of the whole width of the brushes should bear on commutator. When brushes are set on

commutators of direct current dynamos, they should usually be diametrically opposite each other and then placed evenly so that every part makes true contact. There should be no dirt on contact surfaces, for if there is, severe sparking and heating will result. Brushes should rest upon commutator with slight pressure, but not enough to cause undue cutting or heating. They should be removed at regular intervals for inspection and cleaning and if necessary, placed in a brush jig or form, and filed to a proper bevel, as brushes will, even with the best care, wear uneven, burr and collect dirt. To remove dirt and grease from brushes, soak them in gasoline or benzine. Sparking resulting from the causes above named is usually distinguished from the nature of the spark, which is present at the brush points during the full revolution of armature.

A position known as the neutral point, exists on all commutators of direct current dynamos. This is the position of non-sparking in most cases, and generally varies with the load. If the brushes are ahead or behind this point, the sparking is considerable and can be remedied by shifting the brushes till the non-sparking point is reached. The following is the cause of this shifting of the non-sparking point. The field magnets tend to set up a magnetic field in one direction through the armature and the armature owing to its conductors carrying currents of electricity, magnetize the iron armature core in such a manner as to oppose the magnetism of the field magnets and the resultant field. will depend on the relative strength of the two opposing influences. Such an action called "distortion of the magnetic field" occurs in all direct current dynamos, and tends to shift the field of

force out of its natural position and it is evident that since it is caused by the current carried in the armature conductors, that it varies with the load, thus making a change in position of brushes necessary to keep them from sparking. If there existed no field distortion in dynamos, no movement of brushes would be required.

Though the care and inspection of the brushes has been spoken of, as much must be said of the commutator. No matter now nicely filed the brushes are, or how evenly they are set, or in what cleanliness kept, little will avail, if the commutator is uncared for. A well cared for commutator should have a glaze and polish, and with a good dynamo tender, this is always attainable. Sparking is sometimes caused by what is termed, a "high bar" or a flat bar on the commutator, and can, by close scrutiny usually be detected. At first you are warned by a spark appearing on the commutator, quite different from that caused by dirty brushes. By applying the fingers to commutator, once in every revolution a depression or an elevation will be felt. Commutators sometimes become "out of true" owing to improperly "smoothing down". This will be noticed by a rise and fall of the brushes when armature is revolved slowly. Again, if brushes are not properly trimmed or if not properly lubricated, the commutator will often present a bright coppery appearance and a disagreeable "sing" will be noticed, and when felt, it will be found rough, and plenty of copper dust will be found on brushes, etc. If in very bad condition commutator should be turned down in a lathe or better than this and without removing armature, a device similar to a slide rest and usually furnished by makers of machines can be used with a narrow cutting tool. If

only in rough condition with no deep groves, sand paper of different sizes from coarse down should be fastened on a suitable block for bearing pressure and applied until smooth. The use of a file, unless in experienced hands, is not recommended as it will often cause fine bits of copper or burrs to lodge in the insulation between the segments and short circuit sections. "Flats" are sometimes caused after arcing on a particular bar has occurred for some time, and if one of the segments is of softer metal than the others, a flat will gradually develop.

From time to time commutators should be calipered and the cross section of copper determined by subtracting the interior diameter of commutator from the exterior and multiply by the mean width of each bar. Excessive heating in commutator other than that produced by local causes, is many times observed and can be accounted for when it is found that commutator bars are not sufficiently large to carry the armature current without heating. Where a light load is constant on a machine, this may not be noticed until the commutator is worn through, but if on the other hand, a heavy load is always demanded, heating will take place, a new commutator should replace the old.

The commutator should be supplied with a suitable lubricant and probably the best for the purpose, is vasolene, which is not only cheap but does the work well. A small quantity should be rubbed on a piece of cloth or canvas or even better, a piece of leather and on the slightest sign of cutting of brushes on commutator, it should be applied. Great care must be taken in keeping copper dust and dirt away from commutator and armature, for if allowed to gather, it will surely make trouble.

In case of trouble with armature, first take a "magneto" described in previous chapter, which should be part of the equipment of every electric light plant, and find whether the windings of the armature are connected in any way to the core of the armature. This is easily done by connecting one terminal to the commutator segments and the other one to the shaft of the armature. If it is possible to get a ring, you may be sure that something is wrong in the insulation of either the commutator or armature, if the trouble has made itself known by a violent flashing at the brushes, and on examination it is found that the fault is not in the brushes themselves and that one or more commutator segments are badly burnt, it may be inferred that the armature coils connected to the segments are out of order. In event of a short circuited armature coil, the particular coil will usually be found to be hotter than its neighbor or even burnt, or in case of an open circuit, the armature will refuse to generate at all. If there is simply a bad contact at the commutator or in the coil itself, there will be considerable local heating at the point of bad contact, which will usually be at the point the armature coil is joined to the commutator lugs. In case of an armature that has been heavily overloaded, it may be found that the solder in the lug connections at the commutator, has melted and thus short circuited the coils, in this case clean out all the loose solder and removes all solder that make connections between commutator segments, so as to short circuit them. Ring armatures are much easier to locate trouble on than drum armatures, but it is hardly advisable for anyone but on experienced man to take any armature and try to repair burnt out coils.

In case it is found that a series arc light dynamo will not generate current after having been started up to speed, the first thing to determine is whether your circuit to your lamps is "closed" or not. If it is "open", that is, if the circuit is not complete, the break should at once be located. In case a circuit seems to be partially open, which may be the case where several bad contacts or a defective lamp are in the circuit, it will often be possible to "ring" through it by means of a testing magneto, and from the fact that the ring of the magneto is much fainter than it should be, we know that the circuit contains much more resistance than usual. The usual testing magnetos as has been previously described, is a simple alternating current generator of small size operated by hand, which when generating current will ring a small bell. The winding of its armature is of fine wire and will generate sufficient current to ring the bell when connected to a circuit containing as high as 20,000 or 30000 ohms resistance. Since the usual arc light circuit seldom has a resistance of over 500 ohms, and owing to the fact that a series wound dynamo will not "build up" on a circuit having any unusually high resistance, it follows that, although we may be able to ring through a circuit, it may be impossible to start the dynamo on it. In many cases of this kind current may be started through the circuit by connecting the dynamo to the circuit and then short circuiting the dynamo by means of a piece of wire until it commences to generate current and then suddenly opening the short circuit where the momentary rise in pressure at the dynamo terminals due to its self-induction will start the dynamo current through the circuit. This plan should only be used as a last resort. Series dyna-

mos for arc lighting are usually provided with a switch which short circuits the series coils forming the field magnets and thus shuts down the dynamo by destroying the magnetism of the fields. This is the proper way to shut down a series arc dynamo, for if the circuit was broken while the dynamo was in operation, the rise in voltage due to the self induction of the dynamo and circuit is likely to injure the armature. For this same reason the field circuit of the usual shunt wound dynamo should never be broken while in operation, for the self induction "discharge" from the field magnet circuit is likely to injure the insulation of the machine.

In stopping a shunt dynamo after a run, the brushes are often lifted from the commutators by careless dynamo tenders, while the field magnet windings are still receiving current from the armature before the armature has ceased revolving and the flash seen at the commutator in such cases shows conclusively that the field coil insulator must be undergoing a much greater strain than when the dynamo is generating its maximum voltage.

A separately excited alternating current arc light dynamo is usually provided with an arrangement which acts as a safety valve for the excessive extra voltage caused by an open circuit in the line. It consists of two pointed carbons connected to opposite terminals of the dynamo. The points of the carbons, between which the maximum voltage of the dynamo will be found, are separated a slight distance, the distance being such that when the dynamo generates an excessive pressure, the current will jump across the points and thus short-circuit the dynamo and save it from possible damage.

The two well known types of open coil armature dyna-

mos for arc lighting are the Brush and Thomson-Houston makes. The regulation of the Brush arc light dynamo is accurate and positive, and is performed in a simple manner. The field magnets which are of the series type and are provided with a shunt circuit of variable resistance between their terminals. In other words, the current in passing from the armature to the lamps has two paths to divide between. The amount of current in either path will depend on the relative resistance of the two circuits and the amount of current through the field circuits may thus be varied to suit the load which the dynamo is to have.

The circuit in multiple with the field magnets has its resistance varied by means of the "Dial regulator" which consists in its simplest form, of a magnet in the form of a selonoid through which the main circuit passes. The core of the selonoid is attached to a lever which varies the mechanical pressure on several piles of thin carbon plates, the usual form of dial regulator having four piles or columns of carbon plates in series, whose resistance will vary with the increase or decrease of pressure applied to them by the lever attached to the iron core of the selonoid. These piles of carbon plates are thus capable of having their resistance varied and being in multiple with the series coils whose resistance is constant, we have a means of regulation. This style of regulator, when given proper attention, keeps the current practically constant at all loads, and should never be allowed to get out of repair. From time to time carbon plates may have to be added, and the contacts and moving parts of the regulator should be inspected often, to insure proper working when needed.

The arc light dynamos such as the Brush, Thomson-Houston, Excelsior, Wood, Edison, Standard, Ball and a few of smaller concerns have been very largely used in the United States but have since been replaced by modern direct and alternating current machinery. The age is tending toward alternating current machines because of their convenience and application to power and lights. But from a historical standpoint it is well to be acquainted with the various types of electrical machinery, their advantages and disadvantages. However, it must be said that there are small concerns throughout the country that are still operating some one type of the above mentioned machines.

The armature consists of but three coils which, in the later type, are wound on a large iron ring, and are thus known as ring armatures, although electrically, they do not resemble the Gramme winding in the least. The three coils are placed equidistant from each other on the ring and each of the three main coils is divided into ten smaller coils in series, five of which are placed on either side of the ring diametrically opposite each other but connected in series. The three terminals of the three main coils on the pulley end of the armature, are all connected to a metal ring which serves as a common junction for the three main coils. The remaining three terminals at the commutator ends are connected to the three commutator segments. The brushes, four in number, are in pairs, the leading brushes of each pair being called the secondary brushes and the trailing brushes are called the primary brushes. The brushes should be set with great care and also the nozzles to the air blast whose office is to direct a blast of air at the point of the brush just as the brush is passing from one segment of the commutator to another and thus reduce the sparking. The regulation is affected by moving the brushes slightly in direction of rotation and also moving the primary and secondary brushes of each pair with relation to each other, which tends to allow the armature to generate more or less current. The usual Thomson-Houston dynamo will not run safely for any length of time on less than about 1/3 its maximum load unless provided with a "light load switch" which simply cuts out a portion of the field winding of the dynamo and thus weakens the magnetism.

The spark at the commutator should vary from $\frac{1}{8}$ to $\frac{1}{4}$ inches long, depending on the load. At full load the spark should be about $\frac{3}{16}$ inches long. Great care should be observed in keeping all dust and dirt from the commutator supports and from all moving parts of the regulators. The automatic movement of the brushes in the Thomson-Houston dynamos is done by moves of a regulator magnet, which is in turn supplied with current intermittently by means of a wall controller located in any convenient position near the dynamo.

The Excelsior Dynamo regulates by means of an automatic cutting in and out of convolutions or windings of the field magnets.

The Wood dynamo and the Standard arc light dynamos both provide automatic regulation by means of shifting the brushes on the commutator of closed coil Gramme ring armature.

The repairs of arc light dynamos are confined generally to the armature and commutator and as a general rule, it will be found that such trouble as may occur, other than that due to over-loads, can be traced directly to carelessness on the part of the dynamo tender, in cleaning dirt and oil from his dynamo. Too much care cannot be bestowed in cleaning and keeping clean all dynamo electric machinery.

A careful dynamo tender is a necessary adjunct to any well regulated electric light plant, and a greater mistake cannot be made than to place inexperienced men in charge of high voltage machines.

An arc light dynamo may "flash" if carrying too heavy a load or if oil or dirt is present on the commutator and brushes.

Arc light dynamos of all types which generate pressures of 500 volts and over, should be handled with care, and it is always advisable to use rubber mats to stand on, when adjusting brushes, etc., while the dynamos are running. It is also a good plan to make it a rule never to use both hands if it can be avoided, in handling arc lamps, dynamos, transformers, etc., on live circuits. By placing one hand in the pocket and keeping it there when working on circuits of high pressure, there will be little chance of injury from touching two points at the same time in a circuit having a high difference of potential. It must of course always be understood that it is extremely foolhardy to touch any part of a lamp or wire on a live circuit, unless standing on a thoroughly insulated floor, or in case of outside lamps on live circuit, a wooden box should always be used to stand on when adjusting them. Many fatal accidents have occurred through carelessness or neglect on the part of men not following these directions.

Series wound dynamos may have their field magnets partially short circuited by over-heating and this will usually show itself by the machine refusing to generate its usual current. Rewinding the field magnets is the usual remedy. Portions of coils may be cut out by grounding on the core or frame of dynamo in two places. This can be located by means if a magneto or a simple battery and bell.

If a shunt wound machine when running separately from other machines, refuses to "build up" open the main switch leading from dynamo, and usually the trouble will be righted, which in this case was probably caused by a short circuit of some nature on the external circuit,

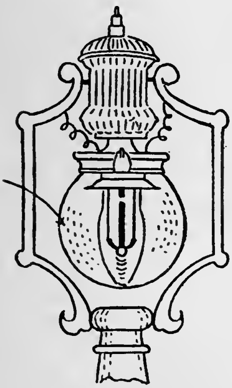
If the machine refuses to generate after opening switch, look for trouble in socket of the pilot lamp. The reader will understand that when a large motor is not revolving, the resistance is low, and if a shunt dynamo should be started up with this motor connected, it would likely refuse to generate, consequently many motors now made are provided with a magnetic retaining switch which automatiically disconnects motor from circuit when current for some reason, is thrown off. Again there may be an open circuit in the 'field magnets, or the magnetism (residual) may have become reversed by the close proximity of another machine. It will be noticed, if tried, that under these conditions, there will be little magnetism exhibited, even less than when machine is not running, being due to the neutralizing effect of the residual and current magnetism.

Seek first to understand the principals upon which your machine depends, as it is then more possible to remedy the troubles that your machine is subject to. Field magnets, armature, commutator and current collecting devices make the dynamo. Understanding each of these you understand the whole. If the reader will grasp the facts in the preceding chapter, he can much easier cope with the troubles that will likely come.

CHAPTER VIII.

ARC LAMPS FOR DIRECT AND ALTERNATING CURRENT. INCANDESCENT LAMPS.

One of the most common uses of the electric current, is for illumination by means of the arc lamp; and a rather detailed account of what should be expected of an arc lamp, will be of interest to every man in charge of dynamos used for either arc or incandescent lighting.


ARC LIGHT.

By far the greater number of arc lamps in use today are supplied from constant current dynamos. That is, a dynamo generating practically a constant number of amperes, and a voltage that varies with the number of lamps in the circuit. These dynamos may be of either the direct or alternating current type. A 125 arc lamp dynamo was exhibited some years ago the voltage of which would be about 6,250 volts when running the 125 lamps. The current was 9.6 amperes. Assuming that the reader is fam-

iliar from study of previous chapters of the difference between constant current and constant potential dynamos, it will be evident that an arc lamp operating on a constant current dynamo, must have a mechanism capable of performing several different functions. The "Voltaic arc", which is so called from the noted philosopher, Volta, is formed in the usual arc lamp by separating the points of two carbons from $\frac{1}{16}$ to $\frac{3}{16}$ inches, through which

FIGURE 30.—VOLTAIC ARC.

current is passing and when supplied from a suitable source of electricity, the current instead of being broken, jumps the space between the carbon points and generates intense heat, which makes them emit the usual dazzling light, known as the arc light.

Figure 30 shows the appearance of the arc as viewed through a pair of dark glasses. The light is not given

out directly from the current as it passes from one carbon point to the other but is given off by the intensely heated carbon points. The cut shown is the appearance of an arc when supplied from a direct current dynamo and when supplied with alternating current, the form of the points and the diffusion of the light is quite different.

In case of lamps being supplied with direct current, the positive carbon burns practically twice as fast as the negative carbon and gives out a great proportion of the light. The positive carbon being the hottest and giving the most light, it will always be found to be the best plan to have the upper carbon positive and thus get the benefit of most of the light by having it thrown down.

In the alternating current arc lamp however, the light thrown off by the upper carbon is the same as from the lower. This will be evident when we consider that the carbons are changing their polority with each alternation of the current, and that for this reason both carbons will be at the same temperature and give out practically the same amount of light. It will thus be seen that unless provided with a reflector over the arc, that as much light will be thrown up in the air as will be thrown down from the lamp where it can be used.

The candle power of the arc will depend on the energy expended in the current passing from one carbon to the other. This is easily represented in watts, which will be the product of the number of amperes and volts. The voltage at which most makes of carbons give the best results is from 40 to 50 volts and most arc lamps for work on direct current dynamos are designed to keep the carbons far enough apart to maintain at least 45 volts be-

tween the carbon points, when proper current is passing. Assuming that a lamp has a difference of potential at its carbon points, of 45 or 50 volts, a constant current of 6.8 amperes passing from one carbon to the other will produce what is known as a 1200 candle power arc lamp or a lamp taking 9½ or 10 amperes at 45 to 50 volts, is known as a 2000 candle power lamp, and the large majority of arc lamps in use will be found to be 10 ampere lamps rated at 2000 candle power. The 1200 candle power lamps spoken of, may also be known as an arc lamp taking from 300 to 340 watts, depending on the variation in voltage between 45 and 50 volts. The 2000 candle power lamp takes usually about 450 watts, and it should be borne in mind that the watts used in any arc lamp is the true key to its candle power.

With a good grade of American made carbon, the arc at 45 volts should be about $\frac{3}{16}$ inches long and burn perfectly quiet without the slightest "blazing," "flaming" or "hissing." With the usual grade of carbon mentioned, a lessening of the distance between the points of the carbon so as to reduce voltage below 43 or 44 volts, will cause a peculiar "hiss" to be heard. This hiss stops as soon as the carbons are separated again to such a length as to raise the voltage to 45 volts.

If the length of the arc is increased to any extent, another effect known as blazing will be noticed. The voltage usually rises to 50 or over before a good grade of carbon will blaze or flame. It is thus seen that the voltage of an arc lamp on direct current should be kept between the hissing point and the blazing point of the carbon, to give a steady and satisfactory light and inasmuch as the carbon is always being consumed when the lamp is burn-

ing, suitable means must be provided, *first*, to separate the carbon points when the current is turned on, *second*, to keep the carbon points a proper distance apart to maintain a steady light and *thirdly*, to cut the lamp out of circuit when the carbons have been consumed or or when any accident has occurred to disable the lamp. These three functions of the lamps mechanism have been developed in many different ways, a few of which will be mentioned as illustrating the practice of to-day in arc lamp construction.

The general principle of all arc lamp feeding mechanism may be more readily understood by looking into what is taking place. Assuming that we have a pair of plain carbon rods, figure 30, one above the other between whose ends the arc has been established. As the carbons burn away, the length of the arc increases and so does the resistance. If the current in amperes remains constant and the resistance is increasing, it is evident that the voltage must be increasing with the resistance. Now if we have connecting the carbon points, a shunt circuit of very high resistance as compared with the arc, and this shunt resistance is made up of a very large number of turns of fine wire around an iron core, it is evident that the more resistance the arc itself contains, the more the current through the shunt will be, for we know that the current divides according to the relative resistance of the two paths shown. Thus, as the voltage increases, the magnetism must also increase and we here have a means for operating feeding mechanism for regulating the strength of arc and maintaining a practically uniform voltage at the carbon points.

The perfecting of the feeding mechanism of arc lamps

has been the work of some of the brightest intellects the country affords, and to-day we will find that there are several general types of lamp feeding mechanism used, most types being fed by the actions of one or more magnets on a releasing mechanism and all types having an upper carbon rod to which the carbon that is fed, is attached. We will describe a few lamps used for series arc lighting.

The first type and the one most generally used, is known as a "Clutch" lamp. A retaining device, termed the "clutch" grips the upper rod and raises it the proper distance to separate the carbon points, and form the normal length of arc of probably 45 volts. As the carbon burns away, the length of the arc increases and the voltage gradually rises until the shunt circuit magnet is so strengthened as to slightly loosen the grip of the clutch, and the rod, owing to its weight, slips down and thus reduces the length of the arc, which weakens the shunt magnet and thus causes the clutch to grip the rod again and hold the upper carbon rod stationary. In this type of lamp, a "series coil" will nearly always be found which carries the main current that flows from one carbon to the other and which is always magnetized when the lamp is in operation. This coil separates the carbons on starting the lamp and usually has no other office.

In differential arc lamps, the series coil is wound on the same spool with the shunt and the windings are so connected that the series winding opposes the shunt, and the resultant magnetism will be the strength of the shunt minus that of the series, the shunt winding current of course increasing with the length of the arc. In this lamp the series coil separates the carbons to the point

where the shunt winding strengthens to such an extent as to make any further separation impossible. The increase in the shunt as the arc lengthens tripping the

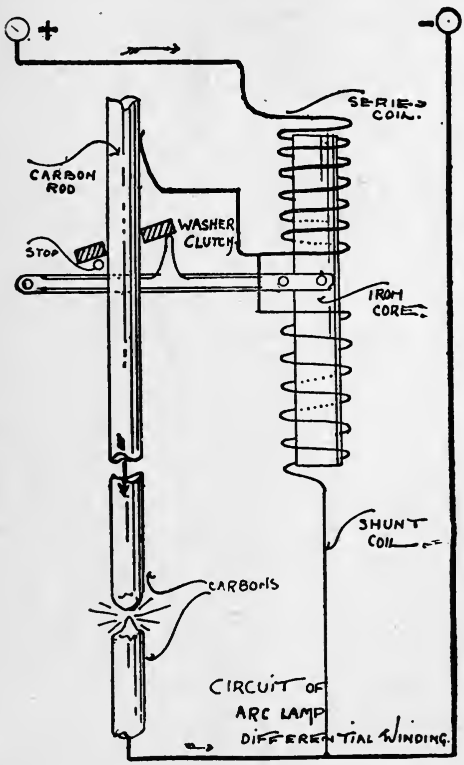


FIGURE 31.—CONNECTIONS OF CIRCUITS OF DIFFERENTIAL ARC LAMPS.—CLUTCH TYPE.

clutch. Such an arc lamp is called a Differentially wound arc lamp. The same effect may be obtained by winding the shunt on one spool and the series on another

with the magnetic action opposing each other. The well known American clutch lamps, operated in this way with differential magnets are the Brush, Wood and Western Electric.

Two well known clutch lamps, the Thomson-Houston and the Standard arc lamps depend on simple shunt magnets to release the clutches.

In the Thomson-Houston, or the "T. H." lamp as it is often called, a separate series winding is put on the outside of the shunt winding and is used solely to separate the carbons, after which it is cut out of circuit until the carbons are to be separated again. This is not what would be called a differential lamp. The Standard arc lamp has a separate series coil which is always in circuit when the lamp is burning and simply separates the carbons, and the shunt spools do the releasing of the clutch.

The Geared lamp, another well known type of arc lamp has a train of gearing and an escapement connected to the upper rod. The weight of the rod being enough to operate the gear, the magnets being used to separate the carbons and stop and start the gear according to the length of the arc. The Wood Geared lamp, the Excelsior and some other makes of lamps not as well known, are of the geared type.

In general, it will be found that geared lamps are more liable to trouble than clutch lamps when placed in exposed positions, owing to the fact that the escapements and racks cut on the rods usually found in this type of lamp, often becomes clogged with dirt. When placed in protected positions however, they may give good satisfaction and furnish a steady light. Nearly all lamps now on the market for use on constant potential circuits are of the geared type.

When lamps are to be run on constant potential circuits, they are usually furnished with a special grade of carbon and when placed on 110 volt circuits, are connected generally two lamps in series with 1½ or 2 ohms of resistance wire, and these pairs of lamps with resistance, then take from six to ten amperes at 110 volts. The office of the resistance is not only to cut down the voltage to about 90 and thus provide a proper voltage for the two lamps to run on, (two lamps, each taking 45 volts, using the 90 volts,) but also to provide a regulating action which tends to make the lamps pass a uniform amount of current through them. The necessity for such action will be appreciated by placing an ammeter in circuit with a pair of lamps when operating on a constant potential circuit of 110 volts, as is usually used in incandescent lighting. Whenever a lamp feeds, it will be found that the current at once rises in the lamp circuit, for when a lamp feeds its carbons together, the resistance of the arc is lessened and there being a constant voltage at the mains, the current at once increases. By placing a constant resistance in series with the lamps, the effect of one of the lamps feeding, does not have as much influence in increasing the current as would have been the case, provided the two lamps were operating on a constant potential circuit of 90 volts. The usual type of constant potential arc lamp when designed for operating two in series on 110 volt circuits, has a differential feeding mechanism, but there are one or two types which use a simple shunt magnet for not only forming the arc, but for feeding the carbons.

In this case, the carbons are always separated when the lamp is not burning and the instant the current is

turned on, the shunt magnets are energized and form the arc. As a general rule, constant potential arc lamps are not nearly as reliable as series arc lamps, for several reasons. The constant potential arc lamp has, as a general rule, been brought before the public by companies formed within the last few years for the especial purpose of manufacturing this class of arc lamp. Having had no previous experience in arc lamp construction, they have often turned out inferior made lamps, although in many cases to-day, they will compare favorably with the standard makes of series lamps, which are manufactured by companies long before the electrical public.

The constant potential arc lamp thoroughly and successfully fills a place which the series lamp does not, but there is also an immense field for the series arc lamp that the direct current constant potential arc lamp cannot touch.

In many towns, the amount of lighting is too small to pay dividends on both an arc light plant of the series type and an incandescent plant also, and it is certainly a commercial success to furnish both arc and incandescent lighting from a constant potential incandescent lighting dynamo, whether it be of the direct or alternating current type.

It is also a great advantage to be able to pay for your arc lighting on the meter basis, and until recently the only practical meters were those used to measure constant potential current.

Another advantage of constant potential arc lamps, is that when it is desired to turn them off it may be done as easily as in the case of the incandescent lamp and of course on a meter basis, when your lamp is turned off, the expense stops.

The fact must be acknowledged that there is a loss of from 150 to 200 watts in the resistance in series with the pair of lamps when they are in operation, but the increased efficiency of the incandescent dynamos over the usual series arc machine helps to make up the difference.

The constant potential arc lamp for alternating currents has been greatly improved during the past year, and there are to-day several makes of alternating lamps that will give satisfaction under all usual conditions.

One great objection to the alternating current arc lamp has been that the humming noise given out by both the arc itself, and the magnets used in the feeding mechanism was so great that the lamps were not satisfactory for inside work.

The use of a better grade of carbon and a mechanism with fewer moving parts, has in a measure overcome this objection. It was found that the shorter the arc, the less humming noise was given out by it and the practice to-day. is to use a carbon which will burn without hissing at about 28 volts, and use a special transformer which gives about 32 to 35 volts on the secondary and operate the lamps on this circuit. A small resistance is usually placed in series with the lamp. The lamps usually take from 10 to 15 amperes, depending on the candle power desired.

The reason for a magnet in the alternating current lamp emitting a humming noise, may be briefly described. If a magnet coil carrying an alternating current, has for its core a bundle of loose iron wires, each alternation of the current will tend to set the individual wires in vibration and it is this effect which often makes a magnet, carrying alternating current, emit a humming

noise. For this reason transformers will hum unless the core stampings are tightly bound together so as to prevent this vibration.

If a coil which is to carry an alternating current is wound on a metal spool, it should be slit so as to prevent

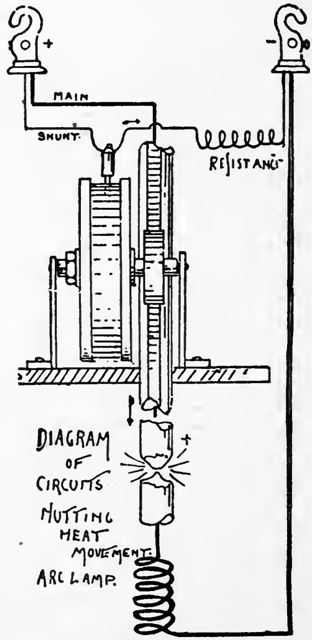


FIGURE 32.—DIAGRAM OF CIRCUITS OF HEAT MOVEMENT LAMP.

current from being generated in the spool, which might otherwise act as a secondary coil of a single turn. The feeding mechanism of alternating current arc lamps should be as free from magnets as possible for any magnet especially with an iron core will have sufficient self induction which, if it be a series coil, will act in a great-

er or less degree so as to choke back the current in the circuit. Then again as the same series coil will not act the same on 16,000 alternations per minute as it will on 15,000, the lamps will have to be adjusted different for each variation in the number of alternations found in various plants.

The heating effect of an alternating current of a given strength however, is the same as the same amount of direct current, and various methods of feeding arc lamps by means of heat generated either at the arc itself or by passing the main or shunt current through a resistance have been experimented with. The heat generated by passing a current through a resistance will vary with the square of the current, or in proportion to the watts used. Thus if we pass two amperes through five ohms resistance, we will be expending 20 watts ($C^2R=(2\times 2)\times 5=20$, if now, the current is increased to four amperes, we will find that although the current is doubled, that the watts expended and thus the heating effect will be increased four times the watts, being 80. One arc lamp in which the plan of a heat feeding mechanism is thoroughly worked out, is the lamp manufactured on the Nutting "heat movement" patents whose feeding mechanism is purely a heat movement. The lamp is also probably the only practical lamp whose feeding mechanism feeds the carbons continuously while burning, although the rate of feed may vary considerable.

The plan of the lamp may be understood from figure 32 which shows the plan of circuits. The lamp uses a shunt circuit for its feeding and separates the carbons in starting the arc by pulling down the lower carbon by means of a series arc drawing magnet in the bottom of the lamp.

The shunt circuit has a total resistance of about 1200 ohms, a portion of which is wound around a heating pin, one end of which is embedded in the surface of a wax disc which is mounted on a shaft and geared to the upper rod. The pin being stationary, the wax disc is not allowed to turn until the heat of the current passing through the heating pin melts the wax around its end.

The pin being in the shunt circuit, will carry more or less current as the arc is longer or shorter and as the heat in the pin varies with the square of the current passing through it, the field is very sensitive and constant. The end of the pin does not plow a furrow in the wax disc, for the melted wax surrounding the pin fills in behind it and thus a wax disc lasts an indefinite length of time. These lamps may be made for either direct or alternating currents of constant current or constant potential type.

A very important and at the same time a very little thought of subject in connection with arc light, is that of carbons. A good carbon is an absolute necessity in obtaining good results in arc lamps, and a carbon which will give good results under one condition, may not in another. A soft carbon usually burns faster and gives a steadier and more perfect light than one that is hard.

A "coppered" carbon burns much longer than the same size and make that does not have a copper coating. The higher the quantity of current to be carried in a carbon, the larger its diameter or the harder its texture should be. If the burning carbons are exposed to a wind, they will burn much faster than in a still atmosphere, and for this reason, if for no other, the globe should be added. For constant potential lamps either for direct or alter-

nating currents, a special carbon should be used. For direct current work, a cored carbon should be used for the upper or positive carbon and a solid carbon for the lower. A cored or treated carbon is usually a moderately hard grade of carbon having a core or hole extending through its length. The core of the carbon is a much softer made carbon than the main carbons. This hole in the positive carbon forms a permanent body and crater, and thus steadies the arc. The core being softer, makes an arc that is longer and less noisy than a hard solid carbon. In alternating current lamps, cored carbons should be used for both upper and lower carbons, to obtain the best results. At present, foreign carbons made in Germany and Austria, are being sold in large quantities in America for constant potential lamps. Their advantage over American makes, are longer life, better light, less dust and dirt and altogether a much better made carbon than the American makes. This is largely due to the fact that American carbon manufacturers have not experimented sufficiently as yet, to make as finished a product as the foreign makes.

INCANDESCENT LAMPS.

The incandescent lamp is so called, from the fact that a filament usually made of carbon, is heated to incandescence by the passage of a current of electricity through it and thus gives out light. The perfection of the incandescent lamp has taken an immense amount of experiment and money, and there seems to be even yet a chance for material improvement in this line.

The first practical incandescent lamp was without doubt made by Thos. A. Edison, and to him and his

associates belongs the most of the credit of bringing the incandescent lamp to its present perfection. The filament of carbon is placed in a glass bulb from which all the air possible is exhausted, the wires connecting the ends of the carbons to the source of electricity being passed through the glass and making an air tight seal with it. The only metal found so far which can be used to maintain a perfectly air tight joint, is platinum, which is a very expensive metal, its value being about that of gold. The reason that platinum must be used, is owing to the fact that it is the only metal which expands and contracts at about the same rate as glass. Inasmuch as the lamp is being heated and cooled as often as turned on and off, it follows that the "inleading wires" must be of this metal to prevent the glass cracking near the wires and letting air into the bulb. The usual lamp used in the United States, is the 16 candle power lamp, although incandescent lamps may be made of almost any candle power from ½ up to 500 or more. The modern incandescent lamp of to-day takes from 2.9 to 4 watts of current per candle power given out and the life will vary from 300 hours in the 2.9 watt lamp to 1200 hours in the four watt lamp.

In studying the most economical method of lighting by means of incandescent lamps, it will be found that the cost of the lamp itself is but a small portion of the cost of 500 or 600 hours lighting and in many cases a three watt lamp would be more economical than a four watt lamp to run, even if the three watt lamp cost $1.00 each and the four watt lamp were furnished free. At two cents per ampere hour at 110 volts, a 16 candle power three watt lamp will use in 600 hours burning, about

$5 20 worth of current. A 16 candle power lamp using four watts per candle power, will have used nearly $7.00 worth of current in the same time. The general public is gradually waking up to this fact and demanding a high efficiency lamp rather than one having a long life and low efficiency. It is evident that an electric light station selling current by meter, can afford to *give* away four watt lamps to its customers rather than have them buy their own lamps of higher efficiency. Generosity (?) of this kind should be carefully investigated.

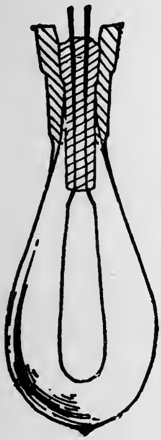


FIGURE 33. WESTINGHOUSE STOPPER LAMP.

Owing to the active legal proceedings of the owners of the Edison patents in America, most of the incandescent lamp manufacturers not leasing from the Edison Company, were enjoined from manufacturing lamps early in 1893, and as a result great activity was shown by various inventors in devising new lamps which did not infringe the Edison patents.

The Westinghouse Electric Company, the largest rival of the General Electric Company, which owns the Edison patents, was one of the first to bring out a new lamp. It has been known as the Westinghoose "stopper" lamp, and the principle may be readily seen from fignre 33. The bulbs in this lamp are provided with a heavy moulded glass neck, in which is fitted a glass stopper which contains the two iron interleading wires. The inner part of the neck of the bulb is ground, so as to make a tight fit with a stopper, which is also ground.

The claim is made that a gas is used in the bulb instead of a vacuum being produced and that the air which may leak in after the stopper is sealed in by means of cement poured over its top is not enough to injure the successful operation of the lamp. This lamp was used for all of the incandescent lighting at the World's Fair at Chicago, in 1893. The Novak lamp is a gas lamp also, the claim being made that bromine gas is used in the bulb instead of the vacuum. Practical tests of this lamp are being made in many places and the results are likely to teach valuable lessons to the lamp manufacturers.

Incandescent lamps using metal filament have recently come into commercial use. Filaments of fine drawn wire of either tungsten or tantalum are suspended in a vacuum similar to the carbon filament lamp. The manufacturing of these lamps is the same as that of the carbon lamp with the exception of the suspension of the filament. The filaments are made much finer and longer than those made from carbon because the resistance of the metal is not as great. The light is much brighter with less power consumption than the carbon lamp—usually about two watts per candle power. Experiments have been made with nitrogen filled bulbs and metallic filaments which have shown a much higher efficiency, about .6 watt per candle power.

The manufacture of the modern incandescent lamp is a science in itself, the high voltage, high efficiency lamp of today has only been perfected by means of hard and costly experiments.

To obtain the best results from any incandescent lamp, it should be run at the exact voltage for which it was made. The filament in a high efficiency lamp at its correct voltage, is heated as hot as it is safe to go without

unduly shortening the life of the lamps, and a rise of three or four volts on a 110 volt lamp is enough to shorten the life of the lamp 100 hours or more.

As a general rule, a low efficiency lamp may be run on a voltage higher than that for which it was designed with less injury than a high efficiency lamp.

In all lamps there will be noticed a "blackening" of the bulb, after having run the lamp for some time. The cause of this blackening of the inside of the bulb, is the basis of several different theories. It is known that it is a thin layer of carbon which is deposited evenly over the entire inner surface of the bulb and it is undoubtedly dependent on the make and grade of filament, and also, on whether the lamp is a "vacuum" or a "gas" lamp. it being claimed that gas lamps do not blacken nearly as fast as the usual vacuum lamp.

The "series" incandescent lamp contains a filament which usually carries a much larger amount of current than the lamps used on constant potential circuits. In an incandescent lamp designed to run on a ten ampere constant current circuit, the filament will be quite large and if it be a "three watt" lamp, the voltage at the terminals of such a lamp, when giving 16 candle power, will be but 4.8 volts or in a 32 candle power lamp, the voltage would be 9.6 volts. On a four ampere lamp of 16 candle power, the voltage would be 12 volts, or 24 volts on a 32 candle power lamp. The lamps would be connected in series of the manner arc lamps are connected. Owing to the danger of handling such series incandescent lamps, they have not been generally introduced for operation on arc circuits, but we find that in America, large numbers of such series lamps are used for street lighting

from alternating current dynamos generating 1000 or 2000 volts constant potential.

In this case, the lamps will be connected in circuits of 40 or 50 lamps each, the lamps are connected in series, and each of these circuits is connected across the high voltage mains. A three watt per candle power incandescent lamp will give about 250 candle power per electrical horse power. A four watt lamp will give about 185. An arc lamp will give at its nominal rating, about 3000 candle power from the same number of watts (746).

Were it not for the fact that the intensity of light given out from a given source of illumination, varies with the square of the distance from the light, the arc lamp would practically occupy the entire field, but the sub-division of light which is possible with the incandescent lamp, often gives a stronger light than the same energy used in arc lamps, in other words, ten 16 candle power lamps properly distributed, will often give a much better general illumination than one 2000 candle power lamp.

CHAPTER IX.

DIRECT AND ALTERNATING CURRENT MOTORS.

The transmission of power by electricity is the most efficient means of transmission for distances of any mention and is displacing steam, compressed air and water power to a marked extent. The losses in these several systems is enormous, but electricity of late years is transmitted great distances with but small loss. Generators, such as have been described, send current over distributing wires which is utilized by machines called motors, in producing mechanical power.

The object of the electric motor is to convert electricity into mechanical or motive power. The electric motor, in form and figure closely resembles and in some cases is identical with the dynamo, and all improvement in design used to make an efficient dynamo, must be followed in motor construction, to obtain the best results.

An electric current traversing a wire near a magnetic needle will deflect it to position at right angles to the flow of current or, a magnet free to move in a magnetic field will tend to set itself in the direction of the lines of force.

A coil of wire carrying a current is pulled around in the direction of the lines of force when free to move in a magnetic field.

In figure 34, a simple form of an electric motor is shown. The current enters the armature by the brushes

which are in contact with a two part commutator, and then passes around the armature coil. The signs + and —, indicating direction of current, as + is current entering and — current leaving.

The field magnets are shown marked N and S. The north pole N attracts the magnet of the south pole of the armature S, and the south pole S of the magnet attracts the north pole N, of the armature. For this reason motion will be given the armature. As the armature nears the position in which the attractive force would have been satisfied, the commutator segments, which are also revolving with the armature, have reached

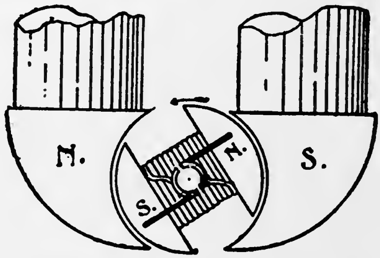


FIGURE 34.—ELECTRIC MOTOR.

a position where the segment which had previously been in contact with the + brush, has now moved so as to be in contact with the — brush, and the opposite segment is now in contact with the + brush.

This must reverse the current in the armature and also the magnetism and the result is that the armature again revolves one-half revolution. This action continues and gives continuous rotation. Such an armature would have a "dead centre" which is of course obviated by placing more coils on the armature. The "torque" or

tendency to revolve, will of course depend on the amount of magnetism in the armature and field magnets, and this of course will depend on the current supplied.

The principle of electric motors applied years ago, consisted in energizing electro-magnets by a suitable battery current, and by the attraction of their magnetic poles, producing mechanical motion of a rotary nature. Later an armature of the Gramme type was placed between permanent magnets and current supplied, which produced rotation. It was noticed that by applying motion to the armature, electric currents were produced and that applying currents to the armature, motion or power was produced. The battery current, at that early period, was found to be unsteady, because soon exhausted and was expensive to maintain. Soon after current from dynamos were supplied to motors at greater economy.

Following this stage of development, it was found that the dynamo could be used as a motor, when supplied with suitable current, and the motor as a dynamo, when supplied with power or motion.

In other chapters, the dynamo was described as generating electric currents by applying mechanical force to rotate the armature. The electric motor is the converse of the dynamo, inasmuch as the motor generates mechanical power by applying electric currents to the machine. Dynamos, when supplied with proper currents run as motors, but not always with efficiency. Commercial motors operate exactly as the one previousiy described, but as this type would not be efficient, it serves only to illustrate the actions in the motor. All commercial motors have a field winding which, when current is passed through it, gives a powerful magnetic field. The arma-

tures are composed of many coils of wire, instead of one, as in the figure, and for this reason no "dead centre" will result. The following statement known as *Lenz's law* is applied to dynamos. "The reaction of an induced current generated by the mechanical movement of a conductor, is always in opposition to the movement"; hence the currents induced in the armature of a dynamo react in opposition to its rotary movement. As explained in another chapter, the power required to drive a dynamo is simply enough to overcome this action, and as the currents are increased or diminished, the engine must exert more or less power by connecting a dynamo already running to another which is to run as a motor, current is thus supplied and produces a force tending to revolve the armature, and if no mechanical force is present to oppose, the armature of motor starts to rotate.

It ought to present itself quite plain to the reader that as the motor armature is turning in its magnetic field, there must be a tendency for current to be generated in the coils, depending on the magnetism, speed, etc., as in the dynamo. Now it is found that when a motor is started up, connected to a constant potential circuit, that it takes a large current from the supply wires and as the speed increases, the current diminishes. The resistance of the armature is very low and from first thought, we would suppose that large currents would be required as the speed increased. But as the current decreases on the circuit as speed increases, the impression is left that there must be a resistance acting in the armature.

In the dynamo, power is applied to the armature to produce current, but the production of current tends to stop the motion given the armature.

Current is applied to the motor to produce power, but the motors own dynamo action as the speed increases, tends to diminish the current applied.

This Electro Motive Force, or counter E. M. F. is proportional to the speed, and acts as a governor, which holds back the current to the motor, but as the motor is called on to do more work, the speed is lessened, the counter E. M. F. is decreased and the current from dynamo is increased and forced through the motor creating a greater torque.

Suppose a number of storage batteries and a dynamo are connected in multiple and both are supplying current to feeders. While the batteries maintain the same E. M. F. as the dynamo, current will flow to the feeder from each, but if the E. M. F. of batteries should fall below dynamo pressure, current will flow from the dynamo to the batteries, opposing them, and a quantity of current supplied the feeder will depend on the pressures of the dynamo and storage battery. The existence of a counter E. M. F. is absolutely necessary. The higher the counter E. M. F., of a motor of given size, the higher its efficiency will be.

Motors are usually built so as to give the best results at certain speeds and voltages. and as a rule a greater or less voltage supplied will lower the efficiency.

Motors for direct current work are distinguished by the manner of winding the field magnets, into series, shunt and compound or differentially wound motors.

The series motors on constant potential circuits, are used mostly for street car work and other places where a strong starting torque is demanded. Small fan motors are generally series wound.

Shunt or compound wound motors are used for stationary work, and their speed can be made practically constant, when supplied with a constant potential current.

Alternating current motors are being rapidly introduced in America and are designed to operate in most cases, on multiphase currents. Single phase motors are usually of the syncronous type, the dynamo current being supplied to the armature windings, but many of the two and three phase motors are designed so that the dynamo currents passing through the field magnet windings only, which produce effects tending to rotate an armature whose conductors are of the most simple form and have no external connections. These are known as "induction" motors, and the Telsa motors so well known are generally of this type.

During the past few years great strides have been made toward perfecting alternating current motors to be used for transmission of power.

The alternating current alone is capable of performing this work in a satisfactory manner, when the amount of power is large and the distance great. The great flexibility of the system is easily seen. By means of an alternating current 100 H. P. generator of 500 or 1000 volts potential, alternating current may be supplied to a "step up" transformer, which may raise the pressure to 10,000 volts and transmit it 25 or 30 miles, where it is then reduced in pressure, to the low voltages used in the motors. The relative amounts of copper used in a 1000 volt and a 10,000 volt distribution for a given distance will be 100 to 1, the relative amount of copper used in a given transmission varying inversely as the *square of the potential at which it is distributed.* It should be possible, in an

alternating current power transmission, to obtain from 50% to 95% of the energy given the generator at the distributing or motor end of the line, the per cent varying with the conditions.

It is a vastly different problem to build a direct current transmission plant using 10,000 volts pressure. In the first place the dynamos would be practically impossible to build, if of any large size, for the problem of insulation of dynamo and motor and their commutators would be most difficult. Transformers, however, may be easily constructed which will withstand this high pressure, and by means of "step up" and "step down" transformers, the dynamos and motors need not be subjected to but a low voltage and they would for this reason, be a much safer and more satisfactory apparatus.

In the synchronous motor, operation is obtained as follows: the motor being simply an alternator reversed. The motor is brought up to the speed of the generator by means of a small starting motor and when the motor is in step with the generator, as indicated by the synchronizer, the switch is thrown, connecting each to each. These machines run very smoothly and stand considerable overloading, when they will pull out of step and stop.

The multiphase motor usually has a closed coil short circuited armature, with no rings or commutators. The windings of the field of the Telsa alternating current motor consists of two circuits traversed by a two phase current of different phases, usually 90° apart, and currents of low potential, are thus induced in the armature, which react on the fields, causing continuous rotation. This type of motor is also called the "rotary field" motor, owing to the rotating magnetic field generated by the

two phase currents in the field windings. The large motors are built on the same plan with windings somewhat altered. These machines start up with great torque on heavy loads.

The general application of the direct current electric motor to street railways, has been almost phenomenal. The first electric railway was first put in operation early in the year 1888 on the Sprague Road at Richmond, Va.

There had before this time been many experiments made, but this road is probably the fiirst one on which the principles now in use were introduced.

The usual car equipment consists of *two* motors and regulating devices for regulating their speed.

The street railway motor is universally a series wound motor, for, considering the requirements of this work, the series wound motor possesses more points of advantage than other types. The motors are supplied in probably 99 per cent of American railways with a constant potential current of about 500 volts pressure. Notwithstanding many newspaper articles in regard to the "deadly trolley" there has yet to be a case reported of an able bodied man being killed or even permanently injured by, a shock of 500 volts. Both of the authors of this book would now have been "planted" several times over, if a 500 or 550 volt shock were fatal.

This uniform agreement on 500 volts as a standard pressure, is practically decided on by all the manufacturers of electric railway apparatus, as a pressure which is not dangerous to life but is as high as is safe to go when difficulties of insulation are considered in both dynamo

and motor construction. The street car motors are often wet and are exposed to a great deal of dust and dirt, and the subject of insulation under these circumstances, is a very perplexing one. Were it not for the extra cost of copper in distributing the current, there is no doubt but that the 500 volt plan of current distribution would be changed to one of lower voltage. The vast majority of electric roads use the overhead trolley system of current distribution, and as been previously described, the rails are bonded and should constitute the return circuit, although often being aided by the low ground resistance.

The conduit systems of electric railways, which consist in placing the conducting wires in conduits under the surface of the street, are now being investigated in America, and it is to be hoped that a simple and reliable system of this kind will be devised to furnish means for operating cars in large cities, where the trolley is objectionable.

Storage batteries have been tried in many places for operating street cars, and with a few exceptions, have not proved satisfactory.

The reasons are many, and some of them are inherent to the system. The storage battery of to-day weighs from 60 to 150 lbs. per H. P. capacity and on a car which may require a considerable power in climbing grades, etc. the batteries are usually a very heavy load, several times in fact, that of motors and equipment of a well designed trolley car.

The batteries are likely to be over-loaded and this results in a reduced efficiency. The net efficiency of the best storage battery system will probably be from 5% to 15% less than a first class trolley system. Some of

these defects of storage batteries will be shown in a succeeding chapter.

There would certainly be many advantages in having a storage battery system of street railways and this should be a practical and commercial process, were it not for the excessive weight in comparison to the output. Each car would be independent of the power house when on the road, and the methods of speed regulation of the motors may be accomplished in a most practical and efficient manner, by varying the number of batteries connected to the motors, and thus vary the voltage applied, and thus the speed.

The usual series motor for street car work, operating on a 500 volt constant potential circuit, may be regulated nsually by one of two ways. The first plan is to have the field magnet windings divided into a number of coils, and these coils which may be connected in several relations to each other, are connected in series with the armature.

By varying the strength of the field magnets by changing the field connections, it is possible to get several different rates of speed. The Edison-Sprague street car motors are wound in this way and by means of a controller switch, the motorman simply varies the connections of the field coil sections, which is done by a partial revolution of an insulating cylinder on which are mounted metal conducting strips which, being against the motor connections, place the terminals leading from the motors, in various combinations with each other. The usual Sprague-Edison equipment of recent design, as furnished by the General Electric Co., has a controller stand or starting switch that has seven different combin-

ations in bringing the car from rest to full speed. The field coil is divided into three sections, each of about equal resistance a, b and c, figure 35.

The connections on the various points are shown plainly in the diagram numbered from 1 to 7.

On the movement of the switch handle from "off" to one, the combination of connections as shown in diagram

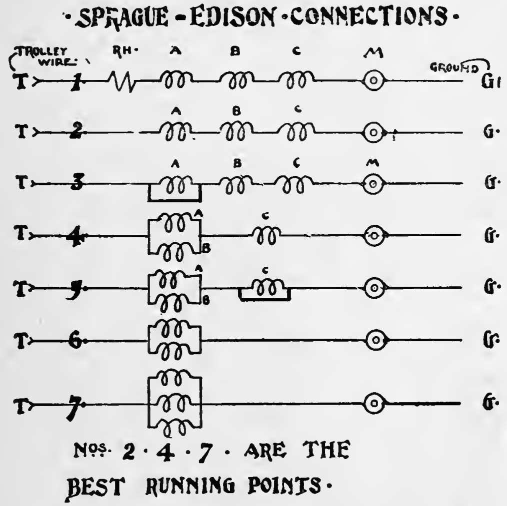


FIGURE 35.—SPRAGUE-EDISON STREET CAR MOTOR CONNECTIONS.

one, is made with each motor under the car. The resistance, Rh., is placed in series with the field coils. a, b and c, which are in series with themselves and with the armature M. The resistance is used in starting the motors, for when the motors are standing still and not producing any counter E. M. F., they would otherwise allow a large rush of current to take place when they were first started.

On the second position this resistance is removed, but

the coils a, b and c, and the armature are still in series relation to each other. The coil a, of the field is now short circuited 3, and in position 4 it is placed in multiple with coil b, thus coils b and c in multiple, are now in series with coil c and the armature. Point 5, short circuits the coil c, which is then cut out of circuit entirely on point 6, thus leaving coils a and b in multiple to furnish the magnetism of the fields. In point 7, the three coils a, b and c are placed in multiple with each other and in series with the armature, and this furnishes the weakest field, and the path of lowest resistance to the flow of current. The motor on this point is exerting its maximum power. Points 2, 4 and 7 are the best "running points", and in operating this system, these points should be used in preference to others. In handling the starting switch, all movements should be firm and steady. If a point is partially passed, move the handle to the next point, never stop between points. In starting a car, let the car start to move on the first point before moving to the second and thus prevent the heavy rush of current which would take place.

The other method of motor control which is in general use, is by means of a variable resistance placed in series with the motor, the fields of which are always in series with the armature and the relations of the coils are not varied except after all the resistance has been cut out of circuit, when the field strength is sometimes weakened by cutting out or short circuiting a section of the field coil, which must of course raise the speed to the maximum. Except at the point at which all resistance is cut out, the efficiency of this method is not usuallyas high as in the commutated field method of regulation, but the

simplicity of the plan is such as to largely overcome this objection, and this plan is used by Thomson-Houston Co. on most of their equipments. The Westinghouse Co. use practically the same methods of motor control on their usual street railway apparatus.

There has lately been revived a method of series multiple connection of motors, which is now being adopted by roads on account of its economy. The motors are two in number, as usual in American street car practice, and they are adapted to be connected in series on starting the motors, which placed 250 volts on each motor. With this manner of connections, the motors will operate very economically at low speeds, such as would be used in going through crowded streets of large cities. When a higher speed is required, the motors are placed in multiple on the 500 volt lines and the motors at once run at a much increased speed. In this method of motor control, the fields are sometimes divided in sections, or as in the usual type of Westinghouse Series multiple controller, the entire changes are affected by varying the connections of the motors and a resistance placed in series with them.

A later method of motor regulation as used by the General Electric Co., consists of a resistance adapted to be placed in shunt or parallel with the series field coils, when maximum speed is desired. This shunt resistance of course robs the fields of part of their current, and weakens them and thus increases the armature speed. The plan of series multiple connections of the General Electric Co., is shown in figure 36, in which 1 and 2 represent the two motors under the car.

The connections as made by the movement of the con-

troller switch, are shown starting with the "off" point, and ending with the two motors in multiple on full line pressure with the field windings shunted by means of the resistance R1 and R2, and thus running at their highest speed. In starting on first point, the resistance Rh1 and Rh2, is placed in series with the motors which are in series relation to each other.

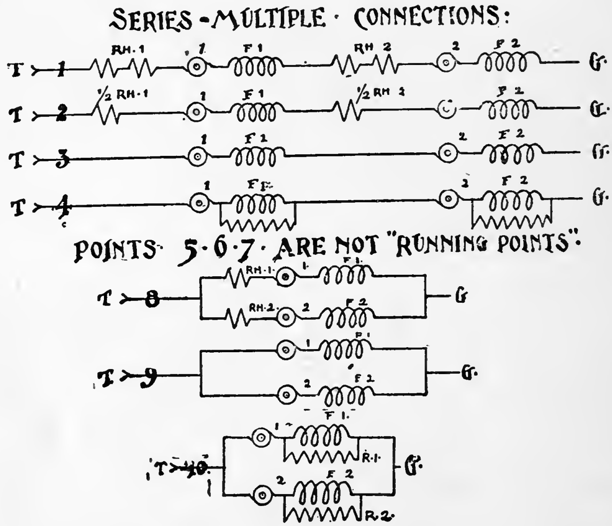


FIGURE 36 —SERIES MULTIPLE STREET CAR MOTOR CONNECTIONS.

On the second point, ½ of the resistance Rh1 and Rh2 is cut out and on the third point, all the resistance in series with the motors is removed, and on the fourth point the field coils are shunted by the resistance R1 and R2. The points 5, 6 and 7, are not running points and are not marked on top of the controller box or stand. During these points, the motors are being changed from series to

parallel relation, as shown in point 8, and from this to the maximum speed point at number 10.

Motors are known in types, as "gearless", "single reduction" and "double reduction", owing to the various methods of connecting the revolving armature to the car axles. A gearless motor is mounted on the axle usually, except in one case where a single large motor is connected to the two car wheels by means of connecting rods, such as are used on locomotives. The gearless and single reduction type of motor has been brought out within the last year or so and to-day the majority of roads use the double reduction motors, which although noisy and necessitating large repairs on the double set of gearing, are usually of light weight for the power developed and are, if anything, more efficient than the heavier slower speed motors.

The single reduction motors of various makes do away to a large extent with the gearing repairs and seem to be the most desirable for the usual street car service. These motors are not excessively heavy and are as a general rule more efficient than the gearless types.

For high speed service, the problem is somewhat different and the gearless motors should be well adapted to this service, for the armature speed would be high and the motor quite efficient. Owing to a lack of room under a car for motors, gearless motors are difficult to build of sufficient power and efficiency that will go in the limited space allowed.

It should be remembered in this connection, that the high speed motor is a much lighter motor for a given power than a slower speed motor. Thus as the armature speed is reduced, the magnetic field must be increased in

strength or the armature coils must be increased in size and number, which means a heavier motor.

Street car motor repairs are often heavy and expensive and in many cases are due to careless handling. The usual street car motor of any make or type is always working under disadvantages compared to stationary motors protected from the weather. The street car motor is exposed to dust and dirt in dry weather, and water and mud in wet weather, and owing to the high pressure used, 500 volts, it is often most difficult to keep armature and fields from grounding and thus disabling them. The frames of the motors are of course connected to the metal car trucks, which are grounded, and in wet weather, water or mud may ground or short circuit the fields or armature of the motors.

"Bucking" is the usual name given to a violent jerk which often takes place when a motor is grounded. Its action is very much like that of a "bucking bronco" and may strip the cogs from the gears or shake up the passengers badly, depending on its severity. If a motor is running at full speed and a ground occurs on the wire between the fields and the armature of the motor, the fields are often made to carry a much greater amount of current than they should. The armature at once begins to act as a generator and "bucks". A flash from brush to brush across the commutator will often cause the same effect. In case of trouble of this kind, look for a grounded field or brush terminal. If the motor is permanently grounded, cut it out and proceed to the barns with one motor. The brushes and commutator of a motor should receive excellent care. In case of sparking, see that your brushes are being pressed against the commutator firmly by the

springs and that they are properly fitted to the commutator surface. Copper coated carbon brushes are superior to those not coppered, for they heat less.

Never reverse a car when running if it can be possibly avoided, and then it should be done in a moderate manner or the fuse is likely to "blow" or the cogs to break, and thus effectually stop all chances of stopping suddenly in this way. In going down grades it is bad policy to run at an excessive speed, experience having shown that several of the worst accidents which have ever occurred on electric railways, were caused by run-away cars on grades. The series multiple controller or starting switches are provided in some cases with a locking switch, which prevents a motor being reversed while current is on the motors. In climbing grades, always run on one of the "best running points", and thus avoid any possible damage from overheating field and armature coils. On a slippery rail, care must be used in starting, to avoid slipping. A moderate use of sand is recommended and in case wheels slip as speed increases, move starting handle back and throw on current again gradually. Go slowly around curves, for your trolley is not only likely to jump off the wire, but broken and damaged trucks are often the result of such reckless running. The trolley pole is also likely to break span wires, etc., of the trolley line.

A motorman should never leave the car without first removing the starting handle from starting box.

Motor cars, if properly designed, should be able to mount grades of 15% to 18% and several roads in America are operating daily on grades of 13% and over.

Incandescent lamps in street cars are usually connected

so as to place five 100 volt lamps in series. Some cars have one set and others two, and as a general rule electric cars are the best lighted of any cars used for passenger transportation in the country. Incandescent lamps, when placed in series, should always be of the same make and candle power, to give the best results. Lamps should not be allowed to become loose in their sockets, for socket repairs are sure to follow.

CHAPTER X.

STORAGE BATTERIES.

Electricity passing through a liquid solution from one metal plate to another will produce chemical action. The action will depend on the quantity of current used, the kind of solution and the material of which the plates are made.

The history of the storage battery or "electrical accumulator" dates back to 1801, when one of the scientists of the day noticed that if two plates of the same metal were immersed in an acid solution and current be passed from one plate to the other, that after they had been disconnected, electric currents could be obtained from the plates by connecting them together by a conductor, the current flowing in an opposite direction to that of the current with which the "cell" had been charged.

No material progress seems to have been made from this date until 1859, when Plante′, while experimenting in this line, made a storage battery consisting of sheets of lead immersed in a solution of dilute sulphuric acid. He found that when currents of electricity were passed though the solution from one plate to the other, that a chemical action was at once set up, tending to change the chemical composition of the lead plates, one of which being connected to the positive pole of a primary battery would gradually assume a reddish color and the other

remaining practically unchanged. He found that after current had been sent through the battery, that it would exert a counter Electro Motive Force, (counter E. M. F.) of from 2 to 2.5 volts and that in discharging the cell, that it would show an E. M. F. of about two volts until there had been given back from the cell nearly the amount of current used in charging it. He also found that by charging a cell and then discharging it, and then reversing the cell and charging it in the opposite direction that its storage capacity would be increased to a large extent, and this process of "forming" the plates was always gone through until the plates became porous and would hold a charge of many times what they would at first. This forming was necessarily a long, tedious and expensive operation, and some time later it was discovered by Faure, that if a paste made of oxide of lead be supplied to a lead supporting plate, called a "grid" that the process of forming was so shortened as to be practically done away with. It also made it possible to reduce the weight of the plates to a great extent and the majority of electrical accumulators or storage batteries used in America are now made on this plan.

It will be evident that it will be necessary in any battery to provide means for keeping the positive and negative plates from touching each other, and thus short circuiting. Various methods have been tried, a few of which will be mentioned. Hard rubber "combs" or "hair pins" may be placed on the plates and thus keep them separated from each other. In one type of battery using pasted plates and "grids" for supporting the active material, plugs of active material in the negative plates are removed in certain places in the plate and rubber

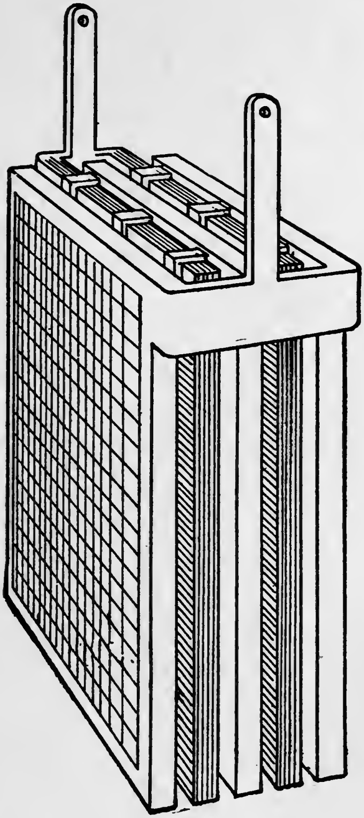


FIGURE 37.—STORAGE BATTERY PLATES.
PASTED PLATE TYPE.

plugs are placed in these openings so as to hold the positive plates away. In other cases a perforated hard rubber plate or a sheet of asbestos paper is placed between the plates. Owing to the "buckling" of the lead plates, it is often a very difficult matter to keep the plates apart,

and in case of contact, the cell will at once become discharged and very likely injured. A deposit of active material often forms at the bottom of the retaining cell and unless the plates are raised some distance from the bottom of the cell, trouble may arise from a short circuit at this point.

It should be understood that no matter how large a single storage cell, either of the Plante′ or Faure type may be, or how many plates it may contain, that its voltage will never be higher than from 2 to 2.5 volts. The "ampere hour" capacity will vary however, with the size and number of plates exposed to the solution, and to get a voltage of say, 100 volts, it will always be necessary to connect at least 50 coils of battery in series, each cell having about two volts E. M. F. There is always a maximum charging rate for a given size plate, which should never be exceeded. A plate when being supplied with more than this rate will be likely to be injured by warping or by being "buckled" as this bending or warping of the plates in called. The cells are rated on their "ampere hour capacity" and each size of cell with its "elements" will have a rate at which it may be charged and discharged giving its maximum efficiency. A well known make of storage battery of 150 ampere hour capacity, may be described as as follows:—voltage about two volts—number of plates 23, 11 of which are positive and 12 negative, thus giving each of the positive plates a negative plate either side of it. The size of both positive and negative plates are the same, $12 \times 6 \times \frac{1}{8}$ inches thick. The normal charging rate is about 25 amperes and the discharge rate from 25 to 30 amperes. The weight of cell and liquid complete is about 45 pounds.

The discharge rate may be slightly increased, but the capacity of the cell will be diminished to a considerable extent.

We have stated that the large number of American made storage batteries are manufactured on the "pasted plate" or Faure principle, but of late many cells of the Plante′ type are being used in America. The mechanical construction however, of the plates is very different from the original Plante′ battery.

In one leading make of the Plante′ type of battery, the plates are formed of lead ribbon whose surface has been previously roughened, the ribbons being about ⅜ to ½ inches wide and placed in a horizontal position between heavy lead end supports. The plate really consists of a large number of thin lead strips, piled one over another until the plate when complete measures in the medium sizes about 6×8×½ inches thick. A number of such plates are then connected by means of lead lugs on the heavy frame of the plates. and in this way a completed cell is put together, and the plates are now ready for "forming". This is done in the usual manner, the peroxide of lead formed from the ribbons fills up the spaces between them and at last forms a practically solid plate of "active material" as the peroxide of lead is called. There is always supposed to be enough of the lead ribbon left to form a support for the active material and when such batteries are properly cared for, they should give good results. They will stand a heavy discharge without buckling and will withstand considerable hard usage such as is experienced in train lighting, etc.

The positive and negative plates of lead batteries, may be easily distinguished by their color, the positive plates

being of a reddish color and the "negatives" of a metallic lead color. When in good condition and fully charged, the "positives" should be of a dark plum color.

The solution of sulphuric acid and water in the plates are immersed will be found to vary in its specific gravity with the charge in the cell. When the cells are completely discharged, its specific gravity should be from 1.15 to 1.16 and when fully charged, its specific gravity will be somewhat greater. The mixture is about $\frac{1}{10}$ acid and $\frac{9}{10}$ water and should be tested after mixing with a hydrometer, which gives the specific gravity. The solution evaporates rapidly when in a cell which is in actual service and water should be added to keep the solution right. If the solution does not contain enough acid, pour in solution already mixed and never pour clear acid in on the plates to increase the specific gravity of the solution.

In charging storage batteries, the positive terminal of the dynamo should be connected to the positive terminal of the series of cells.

In charging the usual lead storage battery, it will be found that until the batteries are almost charged, the electro motive force of each cell will be from 2 to 2.1 volts, but as the charging progresses, the voltage may rise as high as 2.3 volts, but when the charging current is stopped, the voltage falls to about two volts. A low reading voltmeter should be used in testing storage batteries and the terminal reading of a single cell is usually a correct showing of the condition of the cell. If it is found that a single cell tests lower than the others in series with it, the cell should be removed and examined. It may be found that the plates are buckled and in this case they must be straightened again by mechanical means.

The negative plates as a general rule, do not need renewals, but the positive plates are often subject to repairs which cost at least 10% per annum of the original cost of the cell. In many cases of train lighting, the positive plates last but a year on an average, but this service is very severe.

The connections between the batteries and in fact, all corrodible parts of the battery plant should be liberally treated with asphalt paint. All connections should be made in a strong and servicable manner and unusual care taken in insulating all parts of a battery which is to be charged from a high voltage constant current circuit. When charging from a constant potential circuit, a resistance is usually put in series with a set of cells, so as to keep the charging current uniform.

An automatic safety cutout should also be provided, so as to cut out the batteries in case of a dynamo being stopped while connected to the storage batteries, for if this was not done, the dynamo would be supplied with current and run as a motor. A shunt wound dynamo is better adapted to storage battery charging, than the series wound dynamo for several reasons one reason being, that it is not easily reversed by failure of cutouts working, etc.

Although we have spoken of the lead type of storage battery only, there are several other types which are worthy of considerable study. One of these is called the "alkaline" accumulator, and has for its positive plates, a mass of finely divided copper surrounded by a copper wire gauze which holds the copper in position. The plates are then placed in an iron containing cell, which is so constructed that iron partitions come between the

positive plates, but are held away from them. The solution used is one in which potash is dissolved and before the cell is ready for use, a quantity of zinc is dissolved in the solution and held in suspension in it. When the battery is charged, the zinc is deposited on the iron case and partitions between the positive plates, and the copper in the positive plates is oxydized and the electro motive force of the cell will be found to be about $\frac{9}{10}$ volts, much lower than the lead types of battery. When the cell is discharged, the copper oxide is reduced and the zinc on the iron partitions is again dissolved in the potash solution. Although the voltage of the cell is low, its current capacity is high and a cell capable of furnishing about 300 watt hours, will weigh but ½ as much as the usual lead cell. The E. M. F. of this type of cell is quite constant and owing to its small weight and size as compared to the same capacity of lead cell, its application to street car propulsion is to be watched with interest.

The Edison storage battery has recently appeared as a commercial article. Its chief advantage over the lead cell is that it is light and compact and may readily be adapted to traction work. The jar in which the elements are retained is made of nickel plated sheet steel. The electrolyte is a 21 per cent solution of potassium hydroxide. The negative plate consists of iron oxide contained in small receptacles on a metal plate, and the positive plate consists of nickel hydrate contained in small steel tubes held together by a steel frame work. On first charging, the iron oxide is broken up; the oxygen uniting with the nickel hydrate of the positive plate, forming a higher oxide of nickel. On discharging the reverse is true, that is, the nickel oxide is changed to a lower oxide; the oxygen uniting with the iron oxide of the negative plate. The voltage is 1.5 volts, and the Edison cell with the same watt hour capacity weighs one half as much as a lead cell.

Storage batteries cannot be charged by means of the alternating current, a fact which is at once evident when it is remembered that with the current reversing its direction many times a second, a chemical action such as is necessary in any storage battery, would be out of the question. It will thus be seen that the storage battery of any type will always be used in connection with direct current stations, and their value is now becoming generally known in America and Europe. There are many electric light stations supplying low pressure direct current for incandescent lamps, etc., in large cities where current must be supplied at all hours of the day or night. In such a station it will usually be found that during the brightest hours of the day and between midnight and morning, that the load on the station is very light, so light in fact that the smallest dynamos and engines in the station may be under-loaded.

We will find in many such cases as this, that a set of storage batteries may be installed and effect quite a saving in the operating expenses of such a plant. During the hours of the day when the load is smallest, the storage batteries may be charged. Then as the heavy load comes during the early hours of the evening, the batter ies may be connected so as to help furnish current to the circuit and later after the load has lessened to the capacity of the battery, the engines and dynamos may be stopped, and the batteries will furnish the necessary current until morning, when the dynamos are started to carry the daily load. Thus the running hours of the station are not only shortened, but as the dynamos, during the day, are carrying a load nearer their maximum, both the engines and dynamos should operate at a higher

efficiency. By this means, a considerable saving can often be effected, and many central stations and office buildings having their own plants, are now using storage batteries to obtain these results.

By means of the storage battery, a smaller dynamo may be made to furnish current for a much larger number of lamps, for a limited time, than it would be able to carry alone. This is well illustrated in the electric lighting plants installed on some of the steam railroad trains in America. A dynamo, direct connected to a high speed steam engine has a maximum capacity of about 80 amperes at 70 to 80 volts pressure. The incandescent lamps used are 16 candle power and are about 200 in number on a six car train and require about 150 amperes at 64 volts pressure. It will thus be seen that the lamps on the train require 150 amperes of current of which the dynamo can supply but 80, when working at its full capacity, and since the engine driving the dynamo gets its supply of steam from the locomotive, it is often impossible to get any steam at all in certain sections of the road when all the steam in the boiler must be used to operate the locomotive in pulling the train. Thus it will be seen that to maintain a reliable light, a storage battery is the only means which can be used to obtain good results, under such conditions. In practice 32 cells of 150 ampere hour batteries of the lead type, are generally placed under each car and their voltage will thus be found to be about 64 volts for the set of 32 cells.

The dynamo is run continuously, except at such times as the locomotive is disconnected or steam cannot be obtained for other reasons and in this way the batter-

ies are always in condition to supply the current needed in

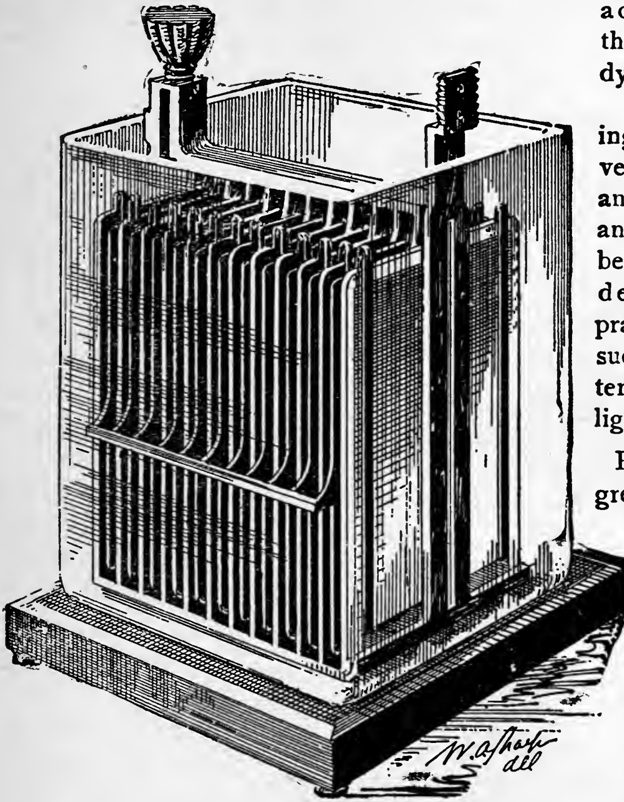


FIGURE 38.—TYPICAL STORAAE BATTERY.

addition to that from the dynamos.

Train lighting service is very severe and much time and money has been spent in developing practical and successful systems of train lighting.

Probably the greatest application of the storage battery — both the lead cell and the Edison cell —is to the electric carriage. The carriage is propelled by a small motor. The chief advantage of the application of electricity to the carriage is the ease with which the carriage may be controlled.

By means of a set of storage batteries from the usual arc lighting circuits of constant current type, incandescent lamps may easily be operated on the usual multiple plan. This would hardly be an advisable thing to do

however, in residence lighting, unless an automatic device prevented the incandescent lamp circuit from being thrown on while the high voltage arc light circuit was charging the cells, for otherwise the handling of the sockets and incandescent lamps might be a dangerous thing to do.

The storage battery has also been used to a large extent for operating small motors in phonographs and other automatic machines. Their use in medical and surgical work is also quite general.

The application of the storage battery to street railway work is at present far from general, but as suggested in previous chapter, the storage battery system is an ideal one and a fortune awaits the successful investigator in this line.

A few points in regard to the care of the usual lead type of accumulator, in addition to those already mentioned, may be of value to those charging or handling them.

Storage battery plates are usually received from the makers after having been formed, and, after having placed the plates in position in their rubber or glass cells and having taken due care in seeing that the positive and negative plates do not come in contact with each other, they should be covered with acid solution of about 1.17 specific gravity and allowed to stand until the solution has thoroughly entered the pores in the plates.

The lead connecting lugs leading up from the positive and negative plates, should be painted with an asphalt paint to keep the acid from attacking the bolts and nuts usually used to connect one cell to another. Care should be taken to scrape the contact surfaces of the lugs and con-

nections between the cells, and thus reduce all needless resistance between the batteries. After a connection has been made, it should be painted with an acid and water proof paint or varnish, to prevent corrosion. The cells are connected in series. The positive plate of one cell connected to the negative plates of the next cell and so on. If the battery is to be charged from a constant potential circuit, care must be taken to allow but a safe amount of current to pass through the battery. The amount of current will depend on the counter E. M. F. of the cells and their resistance. Thus if we are to charge from a 110 volt circuit, we may safely charge from 50 to 55 cells in series, each of the two volts E. M. F. A resistance should always be placed in series with the set of batteries in such cases and in this way be varied to keep the charging current uniform. The amount of current that 110 volts will put through, say, 50 cells will depend of course on Ohms law.

$$C = \frac{E}{R}$$

But E or the number of volts, will be the difference between the counter E. M. F. of the set of batteries and the 110 volt circuit. Thus the voltage of the 50 cells may be 100 volts, in which case E=10 or the difference between 100 and 110. R or the resistance is likely very low, probably not over $\frac{1}{5}$ ohm, and thus

$$C = \frac{10}{\frac{1}{5}} \text{ or } 50$$

which in a cell whose maximum charging rate is but 25 or 30, will be too much. The only way to prevent this excessive flow of current, is to either add extra cells to

the set or place a variable resistance in series with the set of batteries. The larger the size of the plates and the more their number in a given cell, the lower its resistance will be. Knowing the charging and discharging rate of a given battery, and also its voltage and capacity in ampere hours, any problem in the application of the storage battery, may be worked out. New cells should receive several long and steady charges before being put on regular heavy work. The number of amperes multiplied by the number of hours charged, will give the ampere hour charge and new plates after having been dried out in shipment, should be carefully charged the first few times.

A cell should never be allowed to discharge lower than 1.80 or 1.85 volts, and under no condition should a discharged cell be allowed to stand any length of time without recharging, for the plates are likely to become coated with a white coating of "sulphate" which not only injures the plates, but can only be removed by a most careful and tedious process of charging at a low rate.

Buckled cells caused by short circuits or heavy charging or discharging, should be taken apart and straightened by mechanical means. A heavy deposit of active material or "mud" may be found in the bottom of a retaining cell and may be enough to short circuit the bottom of the plates.

Rubber gloves should be used in handling the plates and solution, and woolen clothing should be worn, for cotton goods are soon destroyed by splashes of battery solution. Ammonia may be applied to discolored cloth and will often counteract the effect of the acid.

Great care should be exercised in mixing the sulphuric

acid and water. The acid should be poured in the water in small quantities and should be stirred well as it is being mixed. Considerable heat is always generated under such conditions, and the acid should be allowed to cool before passing over the battery plates.

CHAPTER XI.

ELECTRIC HEATING AND METAL WORKING.

STATION INSTRUMENTS.

Electric heating is a subject that at present is interesting many able workers in the electrical field. Its advantages over coal or gas for heating are many, and its only drawback is its cost when current at the usual lighting rates is used.

The principle of all heaters both for direct and alternating current is that of passing current through resisting conductors which of course consumes energy and exhibits itself in heat. The conductors used in the usual heaters for electric street cars, are generally made of German silver or iron wires, and these wires are in most cases surrounded by some insulating material which is a good conductor of heat, such as fire clay, sand, or enamel. This material really furnishes the wire with a larger heat radiating capacity. It will be evident, for example, that if a heated wire is placed against a plate of cold glass, that it will at once lower its temperature and gradually raise the temperature of the glass. The wire cannot in this case be raised to a dangerous temperature without passing through it several times the amount of current that would melt it in open air. The wires in the usual electric heater, thus carry a much greater amount of cur-

rent without being over-heated, than would be possible without the radiating material surrounding the wire.

In one form of heater. the wires are fastened to an iron plate by means of enamel, the enamel not only completely covering the wires and uniting them to the iron backing but also insulating them from the iron. The wire is in intimate contact with the iron plate by means of the enamel, and of course cannot become much hotter than the iron plates, which having considerable radiating surface, make efficient electric heaters.

One of the earliest forms of electric heaters, patented in the United States, used iron or German silver wires imbedded in fire clay, the whole being incased in an iron box. This form of heater was used in the earliest electric street railway put before the public.

There are to-day about 200 patents on various forms of electric heating and cooking devices. The usual form of electric street car heater, takes from two to five amperes at 500 volts pressure, and after a street car is once heated, from 1200 to 1500 watts of current will provide enough heat for the coldest weather. In a large electric street railway plant, the current will cost about three cents an hour per car to keep the heaters in operation, and this figure will be found to be little if any more than stoves using anthracite coal for fuel. The heaters are usually placed under the seats and are of course out of the way of passengers. A large number of street railways are now using them.

Cooking by means of electricity is being advocated by several companies and without doubt there are many cases where electric cooking devices can be used at a cost of operating about on a par with coal stoves.

Quite a number of patents have been taken out on heaters designed for alternating current work whose operation depends on the setting up of eddy or secondary currents in cores of coils of wire carrying alternating current. Such a heater would not of course operate on direct current circuits.

One of the most interesting applications of heat from electricity is that of metal working and welding.

Electric welding machines are at present doing work that would have been practically impossible with forge and hammer. The Thomson electric welding machines use alternating current for welding purposes by sending an alternating current of moderately high pressure through the primary coil of a large converter, the secondary of which furnishes a current of immense volume at a voltage of but a few volts. The pieces of metal to be united in the weld are placed in the secondary circuit by means of clamps, with their ends in contact with each other. The point of contact being the only appreciable resistance in the secondary circuit, the ends are at once raised to a high temperature. The current is then increased in the primary, and the junction of the two pieces of metal to be welded, is raised to a welding heat. While this heating is in progress, pressure is being applied so as to press the pieces to be welded into even more intimate contact. The whole operation of welding a large bar of iron occupies but a few seconds and the joint made, in many cases is found to be the strongest part of the bar. Many metals may be welded in this way which are very difficult or practically impossible to weld in any other way. Wrought iron pipe bent in various awkward shapes, may be united in this

way in a perfect manner, an operation which is oftentimes very expensive when done in the usual manner. Large crossing frogs and steel rails are often welded on the electrical welder.

The intense heat of the voltaic arc is used to some extent in metal working. The usual plan is to make the metal on which the work is to be done, one pole, and a carbon provided with a flexible conducting cord and handle as the other pole, and form the arc between the metal body and the carbon.

If a piece of metal be connected to one pole of a suitable source of current supply, and a pail of salt water be connected to the other, it will be found that by dipping the end of the metal in the water that it may be raised to a white heat in a few minutes, the water still remaining cool. This may seem impossible at first thought, but nevertheless a fact. A large number of small arcs probably form between the metal and the water, and with metal pieces of proper size, they may be quickly raised to a high heat

SWITCH BOARD AND STATION INSTRUMENTS.

All electrical machinery should, when performing its usual duty, be capable of being controlled, started and stopped in an exact and simple manner, and to know whether a given dynamo or motor is performing its duty, there must necessarily be connected suitable measuring instruments. The proper fitting of a station switchboard is an extremely important consideration, for in many cases, without the use of simple and reliable means of dynamo regulation and control, a station could never perform its proper work. What we cannot see being developed in machinery, we must have indicated by some means.

Every electric light or power station should be provided with all instruments that are necessary for the governing and regulating of its machinery. There should be instruments which indicate the amount of load on the dynamos in amperes, also their pressure in volts.

The dynamo regulating apparatus may be either automatic or performed by means of rheostats, etc. Ground detectors should be used to detect or locate contacts between the wiring or dynamos and the ground. To prevent damage from lighting in the station, lighting arresters are placed on the lines exposed. Switches should be provided to connect the dynamos to the circuits or to make various combinations of the dynamos and thus get various currents.

Fuse or magnetic cutouts are used to prevent a load being applied to the dynamos beyond their maximum capacities.

The switch boards themselves should be made of a non-combustible insulating material, such as marble or slate free from metallic veins, marble being the best possible material usually, for it has high insulating qualities and does not crack or chip as easily as the usual grade of slate generally used. "Marbleized" slate however, is much superior to the usual slate and is largely used. In the score of economy, wooden switch boards are often placed in otherwise first class plants. An oak or pine switch board in a plant using low voltage current, may undoubtedly be made reasonably safe, but it is an exceptional case when one is found, and as a rule a wooden switch board for high potential circuits, when made safe, will cost nearly as much as a slate or marble board.

There should always be from two to three feet space behind a switch board and it should be kept free from waste material from the plant. Station electricians often pile or throw everything imaginable behind them and when trouble comes behind the board, it is a hard job to do anything in a quick manner. Many of the larger electric light companies are building and selling very superior switch boards at reasonable figures.

Rheostats or Field regulators used with shunt or compound wound dynamos provide means of regulating their output by varying the current through the field windings. They usually consist of a series of resistances in the form of German silver or iron wire coils that are connected at several points to contacts on the face of the rheostat, and by means of a contact brush rubbing on their surfaces, more or less resistance is put in series with the dynamo field circuit.

Rheostats of this description are very clumsy, and a better type now produced, is the enamel or cement rheostat in which the resistance wires are imbedded in cement or enamel, only a small amount of wire being required, and that very small in size, as it is well known that a wire imbedded in such a manner will carry a current several times greater than in open air. They occupy but little room and are compact and fire proof.

Quite often in central stations where circuits are unequally loaded, it becomes necessary to raise the potential on individual feeders. To increase the potential of the dynamo would not suffice because circuits having a light load would have too high a pressure. The "booster" for direct current circuits consist of a small series dynamo placed in series with the circuit whose pressure is to be

raised. The conductors on its fields and armature are sufficiently large enough to carry full current. An increase of current in the series field would mean an increase in potential at the armature and this added to the potential of the generator gives the desirable pressure. This machine increases the pressure automatically as the current increases.

For alternating circuits, this scheme is not possible, but the flexibility of the transformers is admirably utilized by Mr. L. B. Stillwell in the Stillwell regulator and described by him as follows: "If each supply circuit receives current from an independent generator, that is, a generator which is called upon to furnish current to other supply circuits, the necessary adjustment of pressure is obtained by regulating the field charge of the generator by means of the rheostat provided for that purpose. If however, several supply circuits are receiving current from the same generator, it becomes necessary to provide means for adjusting the pressure of each without disturbing the others. The regulator consists of a transformer having a secondary coil adjustable in length. Connections are brought out from different points on the secondary coil, to a multi-point switch, by means of which the secondary coil, or any portion of it, may at will, be thrown in series with the supply circuit. When this is done, the electro-motive force due to the whole or a part of the secondary coil of the regulator is added to the initial potential of the circuit. The potential of the supply circuit may therefore be acurately adjusted, independent of whatever may be the potential at the terminals of the generator".

An instrument, the Compensator, is always used with

the regulator and in the same circuit. It consists of a small transformer which supplies current to the voltmeter. The primary circuit has two windings, one of which is on the usual high pressure constant potential circuit and the other is a winding in series with the circuit whose voltage is to be measured.

The secondary circuit supplies current to the voltmeter and when current is flowing, a current is induced on the secondary coil from the primary, which causes voltage to be shown at the voltmeter, corresponding correctly to the voltage at the end of the line with that current. To sum it up, the compensator acts upon the voltmeter to give the potential at the end of the line.

Voltmeters and ammeters are of two general types, those whose reading is due to magnetic effects and those whose reading depends on the expansion and contraction of a wire due to current passing through, and heating it.

The measuring instruments using magnetism, are of various types, some of them using a simple selonoid of wire acting on a movable iron core, to which is attached the indicating pointer. In instruments of this type for use on alternating current, the selonoid spool, if made of metal, is always slit to prevent the spool acting as a secondary coil of low resistance, in which currents would be generated by the passage of current through the coil windings. The iron core of such a coil would have to be laminated, or built up of small iron wires to prevent currents being generated in it.

Other magnetic instruments use the effect obtained by mounting a small armature between the pole pieces of a permanent horse-shoe magnet, and sending the current to be measured through the armature, which tends to

revolve on its shaft and thus produce a movement which gives the reading. Such instruments are usually provided with jeweled bearings and are quite expensive, but the leading measuring instruments of this type, the Weston ammeters and voltmeters, are the standard instruments to-day in America for direct current measuring.

The "hot wire" instruments are mainly used for alternating current work, for since the heating effect of a given current is the same for either direct or alternating current, it follows that such an instrument should be well adapted to the measurement of alternating current.

All high grade instruments should be very carefully handled and in case repairs are needed, it should be done only by one thoroughly acquainted with the work. The rougher classes of cheap instruments are ofted found to be incorrect and it is always policy to calibrate them by means of a standard instrument as often as possible.

In selecting a switch board ammeter or voltmeter, an illuminated scale with large figures is preferable. Deadbeat instruments should be used as much as possible as an instrument whose pointer comes at once to the correct reading and stays there without needless swinging, saves time, and is by far preferable to those whose needle swings to and fro before coming to the exact reading. All instruments should be placed in such a position as to be easily seen by the dynamo tender, but should not be placed in such close proximity to a dynamo, as to have its magnetism effect the reading. In case of it being impossible to place them away from the vicinity of a dynamo, they should be provided with magnetic shields, which may be made in various forms.

Voltmeters should be chosen having as high a resis-

tance as possible, and ammeters should have the least possible resistance, for it will be found that station instruments often take many times more current to operate them than should be used on proper instruments.

In placing instruments on a switch board, care should be taken to so place them that their needles or pointers will be at zero when no current is flowing. Direct reading instruments are always to be preferred to those reading in "degrees", etc. A voltmeter should read directly in volts, and an ammeter in amperes, or a resistance measuring instrument in ohms.

All electric light or power stations having conductors in the open air, must have devices to protect the dynamos from injury from lightning. It should not be understood that lightning must actually strike a line to injure the apparatus connected to it. The majority of cases of trouble from lightning occur from currents of high voltage *induced* in the line by the passage of lightning through the air near or parallel to the line. The voltage is generally very high, and ruined armatures and field coils result unless means for protection are employed.

In many cases the actual damage to the dynamo is caused by the dynamo current following the high voltage lightning discharge, and the damage is done before the dynamo can be stopped. A great deal of time and ingenuity has been spent in devising various lightning arresters. To be reliable, a lightning arrester should always be ready to operate. It should allow the lightning to pass to the ground, but at the same time prevent the dynamo current following. The lightning takes the path of least resistance to ground and will of course break through the system at its weakest point.

The term "resistance" as here used does not necessarily mean the ohmic resistance but the sum of the ohmic resistance and the impedance due to the self-induction of the circuit. A lightning discharge rather than pass through a coil of even very low resistance will often jump a large air gap and pass to the ground.

The lightning arrester usually places a small air gap between the systems and the ground, and this is designed to be the path of least resistance to ground. After a discharge takes place across the air gap to ground the next operation is to interrupt the dynamo current which we have said, usually follows.

This is accomplished in various ways, one of the most common being to place the air gap near the poles of a small electro magnet, which "blows" out the arc by means of the magnetism, it being a well known fact that if a magnet is placed near an arc so that the arc is in the magnetic field that the arc will be apparently blown aside as if it were in a strong current of air. By using a strong magnetic field in this way, an arc may be instantly interrupted and blown out. Another method is to have the air gap over which the arc would start, inclosed in an air tight box and as soon as an arc is started, the confined air immediately expands due to the heat of the arc, and operates suitable mechanism for breaking the circuit.

The air gap may be made between two terminals made of non arcing metal and thus make it impossible to maintain an arc. The non-arcing metal is an alloy lately discovered which apparently on being melted by the arc, forms a gas having a high resistance, for a few small air gaps in series between pieces of this alloy, will rupture an arc on the highest pressure used for commercial electric lighting.

HORSE POWER EQUIVALENTS AT STANDARD EFFICIENCIES.

Current in Amperes at various Standard Voltages.

SIZE OF MOTOR IN H. P.	Kilo-Watt.	Watts.	100 PER CENT EFFICIENCY.					95 PER CENT EFFICIENCY.					90 PER CENT EFFICIENCY.				
			50 Volt.	100 Volt.	110 Volt.	220 Volt.	500 Volt.	50 Volt.	100 Volt.	110 Volt.	220 Volt.	500 Volt.	50 Volt.	100 Volt.	110 Volt.	220 Volt.	500 Volt.
⅛	.093	93	1.86	.93	.84	.42	.186	1.95	.97	.89	.44	.19	2	1	.94	.47	.20
¼	.186	186.5	3.73	1.86	1.69	.84	.373	3.92	1.96	1.78	.89	.39	4.1	2.0	1.88	.94	.41
½	.373	373	7.47	3.73	3.39	1.69	.747	7.85	3.92	3.56	1.78	.78	8.2	4.1	3.76	1.88	.82
1	.746	746	14.9	7.47	6.78	3.39	1.49	15.7	7.85	7.13	3.56	1.57	16.5	8.2	7.52	3.76	1.65
2	1.492	1492	29.9	14.9	13.5	6.78	2.99	31.4	15.7	14.2	7.13	3.14	33	16.5	15	7.52	3.30
3	2.23	2238	44.8	22.4	20.3	10.1	4.48	47.1	23.5	21.3	10.6	4.71	49.5	24.7	22.5	11.2	4.95
5	3.73	3730	74.7	37.3	33.9	16.9	7.47	78.5	39.2	35.6	17.8	7.85	82	41	37.6	18.8	8.2
8	5.96	5968	119	59.5	54.2	27.6	11.9	125	62.8	57.0	28.5	12.5	130	65	60.1	30	13
10	7.46	7460	149	74	67.8	33.9	14.9	157	78.5	71.3	35.6	15.7	165	82	75.2	37.6	16.5
15	11.1	11190	224	112	101.7	50.8	22.3	235	117	106	53.4	23.5	247	123	112.8	56.4	24.7
20	14.9	14920	299	149	135	67.8	29.9	314	157	142	71.2	31.4	330	165	150	75.2	33
25	18.6	18650	373	187	170	84.8	37.3	392	196	178	89	39.2	412	205	187	94	41.2

SIZE OF MOTOR IN H. P.	80 PER CENT EFFICIENCY.					75 PER CENT EFFICIENCY.					65 PER CENT EFFICIENCY.				
	50 Volt	100 Volt	110 Volt	220 Volt.	500 Volt.	50 Volt.	100 Volt.	110 Volt	220 Volt.	500 Volt.	50 Volt.	100 Volt.	110 Volt.	220 Volt.	500 Volt.
⅛	2.3	1.1	1.05	.52	.23	2.4	1.2	1.13	.56	.24	2.9	1.4	1.3	.65	.29
¼	4.6	2.3	2.11	1.05	.46	4.9	2.4	2.26	1.13	.49	5.7	2.9	2.6	1.3	.57
½	9.3	4.6	4.23	2.11	.93	9.9	4.98	4.52	2.26	.997	11.4	5.7	5.2	2.6	1.14
1	13.6	9.3	8.47	4.28	1.86	19.8	9.9	9.03	4.52	1.9	22.9	11.5	10.4	5.2	2.29
2	37.3	18.6	16.9	8.47	3.73	39.7	19.8	18.0	9.03	3.97	45.8	21.9	20.8	10.4	4.58
3	56	28	25.4	12.6	5.6	59.5	29.7	27.1	13.5	5.9	70.8	35.4	31.2	15.6	7.08
5	93	46.5	42.3	21	9.3	99.2	49.6	45.1	22.5	9.9	116	58	52	26	11.6
8	149	74	67.7	33.9	14.9	148	74	72.2	36.1	14.8	183	91	83.2	41.6	18.3
10	186	93	84.7	42.3	18.6	199	99	90.3	45.2	19.9	229	114	104	52	22.9
15	279	139	127	63.3	27.9	298	148	135	67.7	29.8	345	172	156	78	34.5
20	373	186	169	84.7	37.3	399	199	180	90.3	39.9	458	229	208	104	45.8
25	465	232	211	105.6	46.5	497	247	225	112.9	49	574	286	260	130	57.4

The above table has been compiled for the benefit of motor users in calculating wiring necessary for any size motor. It will be found valuable also in ascertaining the exact amount of power that may be expected from a motor using a known number of amperes at any standard voltage —*Compiled by C. K. MacFadden.*

COPPER WIRE TABLE.

Giving weights, lengths and resistances for A. W. G. (Brown and Sharpe) Guage.

GUAGE, To the nearest fourth significant digit.			WEIGHT.		LENGTH.		RESISTANCE.	
A.W.G. B. & S.	Diameter. Inches.	Area Circular mils.	Lbs. per foot.	Lbs. per Ohm. @ 50° C. 122° Fah.	Feet per lb.	Ft. per Ohm. @ 50° C. 122° Fah	Ohms per lb. @ 50° C. 122° Fah.	Ohms per foot. @ 50° C. 122° Fah.
0000	0.460	211,600	0.6405	11,720	1.561	18,290	0.00008535	0.00005467
000	0.4096	167,800	0.5080	7,369	1.969	14,510	0.0001357	0.00006893
00	0.3648	133,100	0.4028	4,634	2.482	11,500	0.0002158	0.00008692
0	0.3249	105,500	0.3195	2,914	3.130	9,123	0.0003431	0.0001096
1	0.2893	83,690	0.2533	1,833	3.947	7,235	0.0005456	0.0001382
2	0.2576	66,370	0.2009	1,153	4.977	5,738	0.0008675	0.0001743
3	0.2294	52,630	0.1593	725.0	6.276	4,550	0.001379	0.0002198
4	0.2043	41,740	0.1264	455.9	7.914	3,608	0.002193	0.0002771
5	0.1819	33,100	0.1002	286.7	9.980	2,862	0.003487	0.0003495
6	0.1620	26 250	0.07946	180.3	12.58	2,269	0.005545	0.0004406
7	0.1443	20,820	0.06302	113.4	15.87	1,800	0.008817	0.0005556
8	0.1285	16 510	0.04998	71.33	20.01	1,427	0.01402	0.0007007
9	0.1144	13,090	0.03963	44.86	25.23	1,132	0.02229	0.0008835
10	0.1019	10,380	0.03143	28.21	31.82	897.6	0.03545	0.001114
11	0.09074	8,234	0.02493	17.74	40.12	711.8	0.05636	0.001405
12	0.08081	6,530	0.01977	11.16	50.59	564.5	0.08962	0.001771
13	0.07196	5,178	0.01568	7.017	63.79	447.7	0.1425	0.002234
14	0.06408	4,107	0.01243	4.413	80.44	355.0	0.2266	0.002817
15	0.05707	3,257	0.009858	2.776	101.4	281.5	0.3603	0.003552
16	0.05082	2,583	0.007818	1.746	127.9	223.3	0.5729	0.004479
17	0.04526	2,048	0.006200	1.098	161.3	177.1	0.9109	0.005648
18	0.04030	1,624	0.004917	0.6904	203.4	140.4	1.448	0.007122
19	0.03589	1,288	0.003899	0.4342	256.5	111.4	2.303	0.008980
20	0.03196	1,022	0.003092	0.2731	323.4	88.31	3.662	0.01132
21	0.02846	810.1	0.002452	0.1717	407.8	70.03	5.823	0.01428
22	0.02535	642.4	0.001945	0.1080	514.2	55.54	9.259	0.01801
23	0.02257	509.5	0.001542	0.06793	648.4	44.04	14.72	0.02271
24	0.02010	404.0	0.001223	0.04272	817.6	34.93	23.41	0.02863
25	0.01790	320.4	0.0009699	0.02687	1,031	27.70	37.22	0.03610
26	0.01594	254.1	0.0007692	0.01690	1,300	21.97	59.18	0.04552
27	0.0142	201.5	0.0006100	0.01063	1,639	17.42	94.11	0.05740
28	0.01264	159.8	0.0004837	0.006683	2,067	13.82	149.6	0.07239
29	0.01126	126.7	0.0003836	0.004203	2,607	10.96	237.9	0.09128
30	0.01003	100.5	0.0003042	0.002643	3,287	8.688	378.3	0.1151
31	0.008928	79.70	0.0002413	0.001662	4,145	6.890	601.6	0.1451
32	0.007950	63.21	0.0001913	0.001045	5,227	54.64	956.5	0.1830
33	0.007080	50.13	0.0001517	0.0006575	6,591	4.333	1,521	0.2308
34	0.006305	39.75	0.0001203	0.0004135	8,311	3.436	2,418	0.2910
35	0.005615	31.52	0.00009543	0.0002601	10,480	2.725	3,845	0.3669
36	0.0050	25.0	0.00007568	0.0001636	13,210	2.161	6,114	0.4627
37	0.004453	19.83	0.00006001	0.0001029	16,660	1.714	9,722	0.5835
38	0.003965	15.72	0.00004759	0.00006454	21,010	1.359	15,490	0.7357
39	0.003531	12.47	0.00003774	0.00004068	26,500	1.078	24,580	0.9277
40	0.003145	9.888	0.00002993	0.00002559	33.410	0.8548	39,080	1.170

Specific gravity of copper=8.89. Resistance in terms of the international ohm, from American Institute of Electrical Engineers Transaction Oct. 1893.

SAFE CARRYING CAPACITY TABLE.

Below is a table showing the safe carrying capacity of different sizes of Brown & Sharpe gauge copper wires and cables of ninety-eight per cent conductivity. Taken from Rules and Requirements of the National Board of Underwriters.

B. & S. Gauge.	Table A. Rubber Insulation. Amperes.	Table B. Other Insulations. Amperes.	Circular Mills.	Circular Mills.	Table A. Rubber Insula. tion. Amperes.	Table B. Other Insulations. Amperes.
18	3	5	1,624	200,000	200	300
16	6	10	2,583	300,000	275	400
14	15	20	4,107	400,000	325	500
12	20	25	6,530	500,000	400	600
10	25	30	10,380	600,000	450	680
8	35	50	16,510	700,000	500	760
6	50	70	26,250	800,000	550	840
5	55	80	33,100	900,000	600	920
4	70	90	41,740	1,000,000	650	1,000
3	80	100	52,630	1,100,000	690	1,800
2	90	125	66,370	1,200,000	730	1,150
1	100	150	83,690	1,300,000	770	1,220
0	125	200	105,500	1,400,000	810	1,290
00	150	225	133,100	1,500,000	850	1,360
000	175	275	167,800	1,600,000	890	1,430
0000	225	325	211,600	1,700,000	930	1,490
				1,800,000	970	1,550
				1,900,000	1,010	1,610
				2,000,000	1,050	1,670

For insulated aluminum wire the safe carrying capacity is eighty-four per cent of that given in the above tables for copper wire with the same kind of insulation.